# HANDBOOK ON
# MECHANICAL STOKERS
## FOR
# SHELL BOILERS

NATIONAL COAL BOARD

LONDON

£3.00

HANDBOOK ON

# MECHANICAL STOKERS

FOR

# SHELL BOILERS

*Published by*

THE NATIONAL COAL BOARD
Production Department
Hobart House
Grosvenor Place
LONDON, S.W.1

*Price 15s.*

*First Published 1952*

*Reprinted 1956*

Printed by Sun Printers Ltd.
London and Watford

# PREFACE

In order to increase the efficiency of existing boiler plants at the collieries, considerable quantities of equipment are bought every year by the coal industry. This process has been greatly speeded up by the decision, made by the Board in Autumn, 1951, to replace hand-firing wherever possible by mechanical stokers. Contracts for large quantities of equipment have been placed and this material is now beginning to be installed.

The provision of modern equipment, however, is only part of the task. Trained men are required for obtaining the best efficiency and for maintaining the new equipment. In addition, the performance of existing plant can be much improved by more skilful operation. Training the existing staff at collieries is, therefore, as important as supplying modern equipment.

This Manual is to serve as a guide in the training courses for boiler house staff now being organised in the industry, and it deals with the problem of how best to burn coal on mechanical stokers. In order to do this, some of the fundamentals of combustion engineering have had to be explained.

Compiled with the help of many manufacturers and prospective users, it is expected that the present volume will bring out many suggestions for improvement of its contents in preparation for a second edition.

# CONTENTS

## CHAPTER VII



## CHAPTER VIII

## ACKNOWLEDGMENTS

We are indebted to the following for their collaboration and permission to publish illustrations of their equipment:—

Bennett Furnace and Engineering Co. Ltd. (Figs. 38b, 81.)

Bennis Combustion Ltd. (Figs. 63, 77-79, 90-94.)

Joshua Bigwood and Son Ltd. (Figs. 115, 121, 122.)

British Doby Stokers Ltd. (Figs. 56, 68, 69.)

Cochran and Co. (Annan) Ltd. (Fig. 3.)

Crosthwaite Furnaces Ltd. (Figs. 55, 80.)

Edwin Danks and Company (Oldbury) Ltd. (Figs. 84-89.)

Davidson and Co. Ltd. (Figs. 29, 30, 32-37.)

James Hodgkinson (Salford) Ltd. (Figs. 62, 108-110.)

Hope's Heating and Engineering Ltd. (Fig. 114.)

James Howden and Co. (Land) Ltd. (Figs. 20, 21, 22, 24-27, 31.)

Metropolitan Engineering Co. Ltd. (Fig. 18.)

The Mirrlees Watson Company Ltd. (Figs. 111, 112.)

J. and J. Neil (Temple) Ltd. (Figs. 44, 45, 66, 67.)

Niagara Engineering Co. Ltd. (Figs. 64, 65.)

Prior Stokers Ltd. (Figs. 126, 127.)

James Proctor Ltd. (Figs. 46-49, 70-72.)

Riley Stoker Company Ltd. (Figs. 116-120, 124, 125.)

Rimer Manufacturing Co. Ltd. (Fig. 107.)

John Thompson (Triumph Stoker) Ltd. (Figs. 1, 41-43, 50, 54, 73-76, 95-102.)

The Turbine Furnace Co. Ltd. (Fig. 51.)

For permission to publish illustrations, we are indebted to H.M. Stationery Office, for figs. 6, 8, 14, 15 and 19; and also to the College of Fuel Technology, London, N.6.

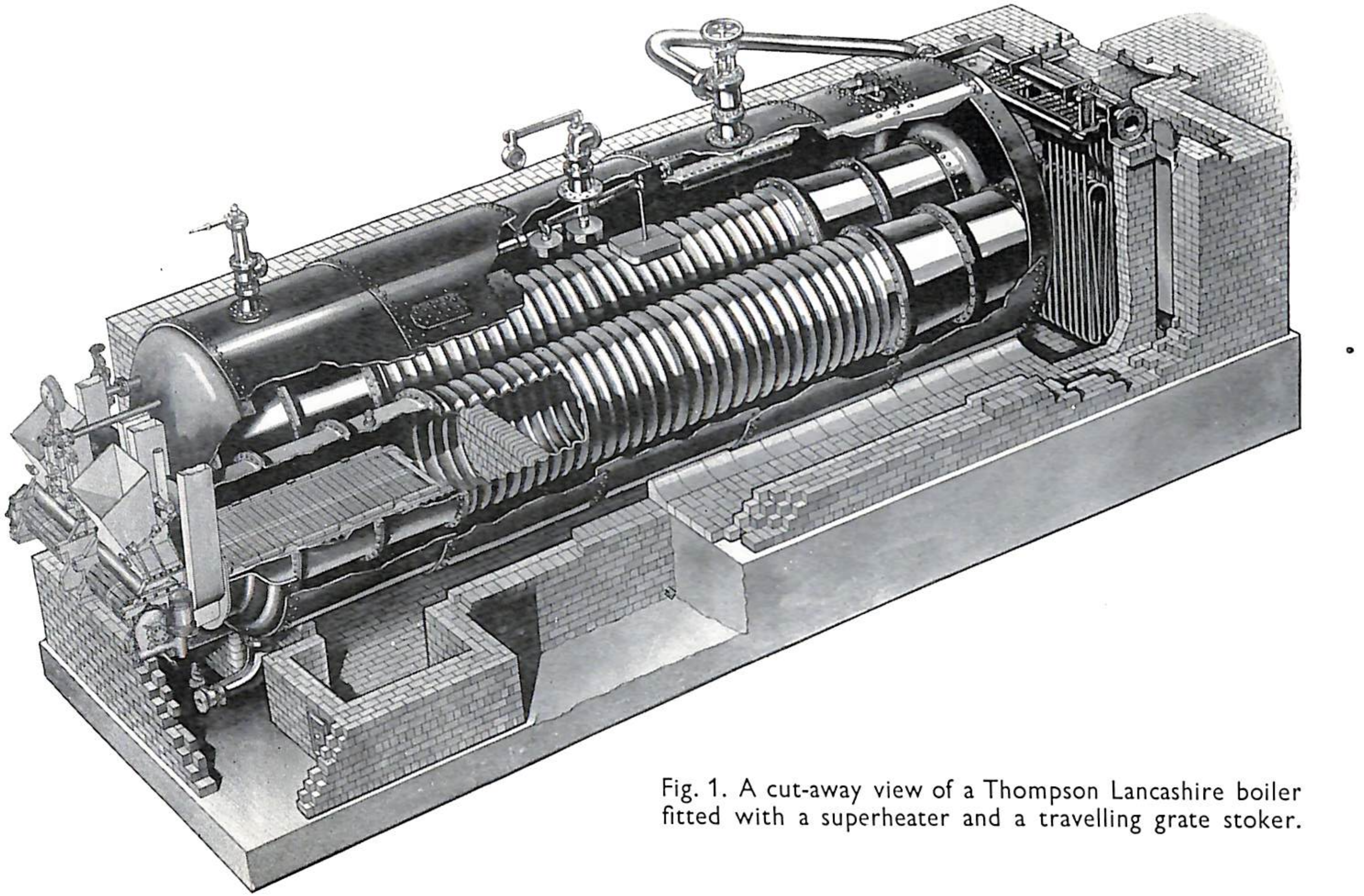


Fig. 1. A cut-away view of a Thompson Lancashire boiler fitted with a superheater and a travelling grate stoker.

# INTRODUCTION

**Shell Boilers.**

There are many kinds of steam boilers. These fall naturally into two principal groups: those in which the furnace is surrounded by water and steam—shell boilers, typified by figs. 1 and 3; and those in which the furnace gases are external to the heating tubes through which water flows—water tube boilers.

Internally fired shell-type Lancashire boilers are widely used at collieries, and are made in units for evaporations up to about 15,000 pounds of water per hour (lb. per hr.). The range of standard sizes is given in Table I.

This Handbook is concerned with mechanical stokers for Lancashire and vertical boilers.

**The Lancashire Boiler.**

A Lancashire boiler has a cylindrical shell which is usually from 6 ft. 6 in. to 10 ft. in diameter and from 24 to 30 ft. long. A common size is 8 ft. 6 in. in diameter and 30 ft. long. This shell is fitted with end plates with two flue tubes fixed between them, into the front ends of which the grates are fitted, as shown in fig. 1.

The boiler is usually mounted in a brickwork setting which also forms flues through which the hot combustion gases flow in contact with the boiler shell in their passage to the chimney. The products of combustion, after flowing through the furnace tubes, enter a downtake in which a superheater may be fitted (fig. 1). They then return under the shell to the front of the boiler where they are diverted into two side flues, formed by the brickwork, thence to the main waste gas flue and on to the chimney. The temperature of the products of combustion in the downtake when a boiler is working at its maximum rated capacity is about 1,200 degrees Fahrenheit (° F.); and when they pass through the side damper openings their temperature is about 850° F. The transfer of approximately 85 per cent of the heat which is transmitted to the water in the boiler occurs through the furnace tubes, about half of this amount being transferred immediately above the fuel bed in the first 10 ft. The remaining 15 per cent is transferred to the water through the shell exposed to hot gases in the bottom and side flues. This heat transfer distribution remains substantially the same over a wide range of firing rates.

The working pressure of a Lancashire boiler seldom exceeds 250 pounds per square inch (lb. per sq. in.) and of the total heat produced from the fuel burned on the grates, from 60 to 65 per cent may be transferred to the water in the boiler. This percentage is called the thermal efficiency of the

boiler. The installation of a feed water heater or economiser to recover some of the heat which would otherwise be lost in the waste gases may add a further 10 to 12 per cent to the thermal efficiency of the plant.

The Lancashire boiler, because of its simple construction, is easy to inspect and clean. It has the largest water capacity and steam-releasing surface per unit of steam produced of any type of boiler, and as the water is maintained at approximately the same temperature as the steam a proportionately large amount of steam can be supplied at peak loads against a fall in pressure. It has, however, two serious limitations:—

(*a*) The combustion space is small, so that it is difficult to complete the combustion of the gases before they leave the boiler. This makes it difficult to prevent the emission of smoke.

(*b*) The total area of the surfaces transferring heat to the water is also limited, so that the flue gas "exit temperature" is relatively high. This disadvantage is overcome when an economiser is fitted.

**The Vertical Boiler**

The vertical boiler in its simplest form consists of a cylindrical vertical shell surrounding a combustion chamber (or fire-box) in the bottom of which is the grate (fig. 2).

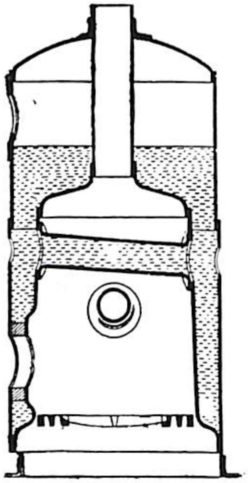


Fig. 2. A cross-section through a cross-tube vertical boiler.

A tube or uptake is arranged from the centre of the crown of the fire-box up through the crown of the shell upon which the chimney is fitted. One or more cross-tubes may be provided, flanged and riveted or welded to the fire-box to increase the heating surface, and inclined to improve the circulation of the water. Handholes give access to the cross-tubes and to the bottom of the water space around the fire-box for cleaning.

There are many designs of vertical multitubular boilers in use. One of the best known is the Cochran, shown in fig. 3. The crowns of the combustion chamber and of the cylindrical outer shell are made hemispherical to obtain the maximum volume and strength for a given weight of plate. The working pressure is normally 100 pounds per square inch. Ready access is provided for the cleaning of the internal surfaces of the tubes.

The range of standard sizes for boilers of this class is given in Table II.

The multitubular vertical boiler is thermally the most efficient of its type, but its efficiency is less than that for Lancashire boilers, and is about 55 per

TABLE I

LANCASHIRE BOILERS: RANGE OF STANDARD SIZES
(Bituminous coal—12,500 B.Th.U. per lb.)

| Size | | Evap. from and at 212° F. lb./hr. | Total coal burned lb./hr. | Coal burned per sq. ft. G.A. lb./hr. | B.Th.U. released per sq. ft. G.A. × 1,000 |
|---|---|---|---|---|---|
| 6 ft. diameter × 24 ft. long. Flue diameter 28 in. Grate area 23 sq. ft. | A | 4,230 | 590 | 25.6 | 308 |
| | B | 4,620 | 620 | 27 | 325 |
| | C | 4,620 | 620 | 27 | 325 |
| | D | 5,060 | 632 | 27.4 | 329 |
| 6 ft. 6 in. diameter × 26 ft. long. Flue diameter 31 in. Grate area 26 sq. ft. | A | 5,050 | 706 | 26.1 | 313 |
| | B | 5,470 | 736 | 28.3 | 340 |
| | C | 5,550 | 746 | 28.7 | 346 |
| | D | 6,080 | 760 | 29.1 | 350 |
| 7 ft. diameter × 30 ft. long. Flue diameter 33 in. Grate area 30 sq. ft. | A | 6,450 | 900 | 30 | 360 |
| | B | 7,000 | 940 | 31.3 | 376 |
| | C | 7,090 | 954 | 31.8 | 382 |
| | D | 7,900 | 985 | 32.8 | 394 |
| 7 ft. 6 in. diameter × 30 ft. long. Flue diameter 36 in. Grate area 33 sq. ft. | A | 7,200 | 1,010 | 30.5 | 366 |
| | B | 7,800 | 1,050 | 31.7 | 381 |
| | C | 7,910 | 1,064 | 32.2 | 387 |
| | D | 8,880 | 1,110 | 33.5 | 403 |
| 8 ft. diameter × 30 ft. long. Flue diameter 39 in. Grate area 36 sq. ft. | A | 8,220 | 1,150 | 32 | 384 |
| | B | 8,860 | 1,190 | 33.1 | 397 |
| | C | 9,040 | 1,215 | 33.7 | 404 |
| | D | 10,020 | 1,275 | 35.4 | 425 |
| 8 ft. 6 in. diameter × 30 ft. long. Flue diameter 42 in. Grate area 42 sq. ft. | A | 9,200 | 1,285 | 30.7 | 369 |
| | B | 9,900 | 1,335 | 31.7 | 381 |
| | C | 10,080 | 1,355 | 32.3 | 388 |
| | D | 11,140 | 1,420 | 33.7 | 404 |
| 9 ft. diameter × 30 ft. long. Flue diameter 45 in. Grate area 45 sq. ft. | A | 10,200 | 1,425 | 31.4 | 377 |
| | B | 10,930 | 1,470 | 32.7 | 393 |
| | C | 11,200 | 1,508 | 33.6 | 403 |
| | D | 12,250 | 1,530 | 34 | 408 |
| 9 ft. 6 in. diameter × 30 ft. long. Flue diameter 48 in. Grate area 52 sq. ft. | A | 11,350 | 1,565 | 30 | 360 |
| | B | 12,120 | 1,625 | 31 | 372 |
| | C | 12,500 | 1,685 | 32.5 | 390 |
| | D | 13,520 | 1,690 | 32.6 | 391 |
| 10 ft. diameter × 30 ft. long. Flue diameter 48 in. Grate area 52 sq. ft. | A | 12,500 | 1,750 | 33.7 | 404 |
| | B | 13,450 | 1,810 | 34.8 | 418 |
| | C | 13,800 | 1,840 | 35.4 | 426 |
| | D | 14,800 | 1,850 | 35.5 | 427 |

A. Hand-fired, natural draught. B. Mechanical stokers, natural draught. C. Special furnaces hand-fired, forced or induced draught. D. Mechanical stokers, forced or induced draught.

cent. The advantage of vertical boilers is that they require the least possible ground space for a given duty, and can be made in smaller sizes than Lancashire boilers.

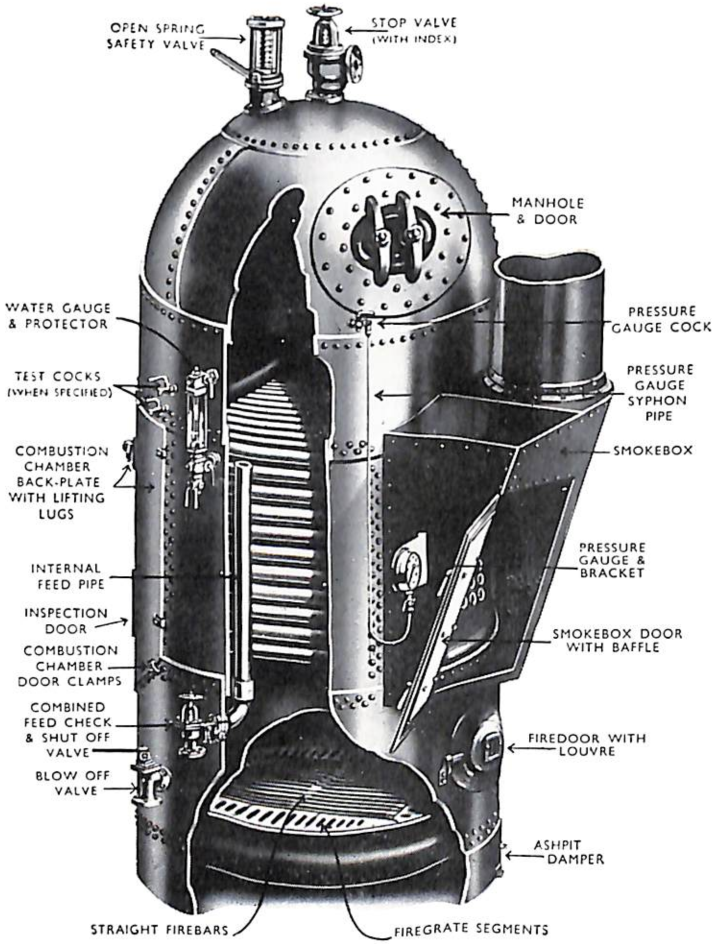



Fig. 3. A cut-away view of a multitubular Cochran boiler.

The hot gases from the burning fuel pass from the fire-box into a combustion chamber which is lined with firebrick against the shell, thence through a bank of horizontal tubes to the smoke box, and to the chimney.

### Hand-Firing.

Hand-firing enables a wide range of coals to be burned effectively on relatively small grates, but it is difficult to fire coal regularly and evenly, hour by hour, by hand. When firing is too heavy, sufficient air cannot pass into the fuel and black smoke is emitted. When firing is too light, too much air may pass through the coal, with a consequent loss of heat and a drop in the thermal efficiency of the boiler.

## Table II

### Vertical Boilers (Cochran): Range of Standard Sizes

These figures relate to bituminous coal (12,500 B.Th.U. per lb.) and to normal steaming, that is 75 per cent of maximum evaporation, the coal consumption being 60 per cent of the maximum.

| Size | | Evap. from 212° F. lb./hr. | Total coal burned lb./hr. | Coal burned per sq. ft. G.A. lb./hr. |
|---|---|---|---|---|
| 3 ft. dia. × 6 ft. 9 in. high. Grate area 4.75 sq. ft. | Heating surface 50 sq. ft. .. | 300 | 42 | 9.1 |
| 3 ft. × 7 ft. 6 in. Grate area 5.75 sq. ft. | Heating surface 60 sq. ft. .. | 410 | 56 | 10 |
| 3 ft. × 8 ft. 6 in. Grate area 7.50 sq. ft. | Heating surface 1,000 sq. ft. .. | 650 | 86 | 11.5 |
| 4 ft. × 9 ft. Grate area 8.50 sq. ft. | Heating surface 110 sq. ft. 3 sq. in. | 755 | 102 | 11.8 |
| 4 ft. × 9 ft. 6 in. Grate area 9.25 sq. ft. | Heating surface 140 sq. ft. .. | 900 | 112 | 12.0 |
| 4 ft. 6 in. × 10 ft. Grate area 9.75 sq. ft. | Heating surface 160 sq. ft. .. | 985 | 121 | 12.4 |
| 4 ft. 9 in. × 10 ft. 3 in. Grate area 11.75 sq. ft. | Heating surface 190 sq. ft. .. | 1,235 | 150 | 12.6 |
| 5 ft. × 11 ft. 3 in. Grate area 12.5 sq. ft. | Heating surface 220 sq. ft. .. | 1,380 | 163 | 13 |
| 5 ft. 3 in. × 11 ft. 9 in. Grate area 14 sq. ft. | Heating surface 250 sq. ft. .. | 1,585 | 187 | 13.3 |
| 5 ft. 6 in. × 12 ft. 3 in. Grate area 16.75 sq. ft. | Heating surface 300 sq. ft. .. | 1,945 | 229 | 13.6 |
| 5 ft. 9 in. × 13 ft. Grate area 18.75 sq. ft. | Heating surface 350 sq. ft. .. | 2,255 | 261 | 13.9 |
| 6 ft. × 12 ft. 6 in. Grate area 18.75 sq. ft. | Heating surface 350 sq. ft. .. | 2,255 | 261 | 13.9 |
| 6 ft. × 13 ft. 6 in. Grate area 18.75 sq. ft. | Heating surface 350 sq. ft. .. | 2.255 | 261 | 13.9 |
| 6 ft. × 14 ft. Grate area 18.75 sq. ft. | Heating surface 400 sq. ft. .. | 2,400 | 261 | 13.9 |
| 6 ft. 6 in. × 13 ft. 6 in. Grate area 22.50 sq. ft. | Heating surface 450 sq. ft. .. | 2,830 | 319 | 14.1 |
| 6 ft. 6 in. × 14 ft. Grate area 22.50 sq. ft. | Heating surface 450 sq. ft. .. | 2,830 | 319 | 14.1 |
| 6 ft. 6 in. × 14 ft. 6 in. Grate area 22.50 sq. ft. | Heating surface 500 sq. ft. .. | 2,975 | 319 | 14.1 |
| 7 ft. × 14 ft. Grate area 26.75 sq. ft. | Heating surface 500 sq. ft. .. | 3,300 | 385 | 14.3 |
| 7 ft. × 15 ft. Grate area 26.75 sq. ft. | Heating surface 600 sq. ft. .. | 3,625 | 385 | 14.3 |
| 7 ft. 6 in. × 16 ft. 3 in. Grate area 31.50 sq. ft. | Heating surface 750 sq. ft. .. | 4,380 | 460 | 14.6 |
| 8 ft. × 16 ft. 6 in. Grate area 37 sq. ft. | Heating surface 850 sq. ft. .. | 5,185 | 543 | 14.6 |
| 8 ft. 6 in. × 18 ft. Grate area 41 sq. ft. | Heating surface 1,000 sq. ft. .. | 5,950 | 602 | 14.6 |
| 9 ft. × 19 ft. Grate area 48 sq. ft. | Heating surface 1,250 sq. ft. .. | 7,235 | 740 | 15.4 |

The first mechanical stokers were designed to prevent the emission of smoke by maintaining an even thickness of coal on the grate, and were spoken of as "smoke-consuming furnaces." The idea of preventing the emission of black smoke by this means first appeared in 1785 in a Patent Specification by James Watt.

**Hand-Firing versus Mechanical-Firing**

A plant consisting of a shell boiler with an economiser can be hand-fired with a thermal efficiency of 75 per cent. This calls for greater skill than is normally available, and it has been estimated that the average efficiency of hand-fired shell boiler plants in Great Britain is less than 60 per cent. This means that about 20 per cent more coal is used than need be. In round figures about 20 million tons of coal are thus wasted each year, and the need to eliminate this waste is the predominating factor in favour of mechanical stoking.

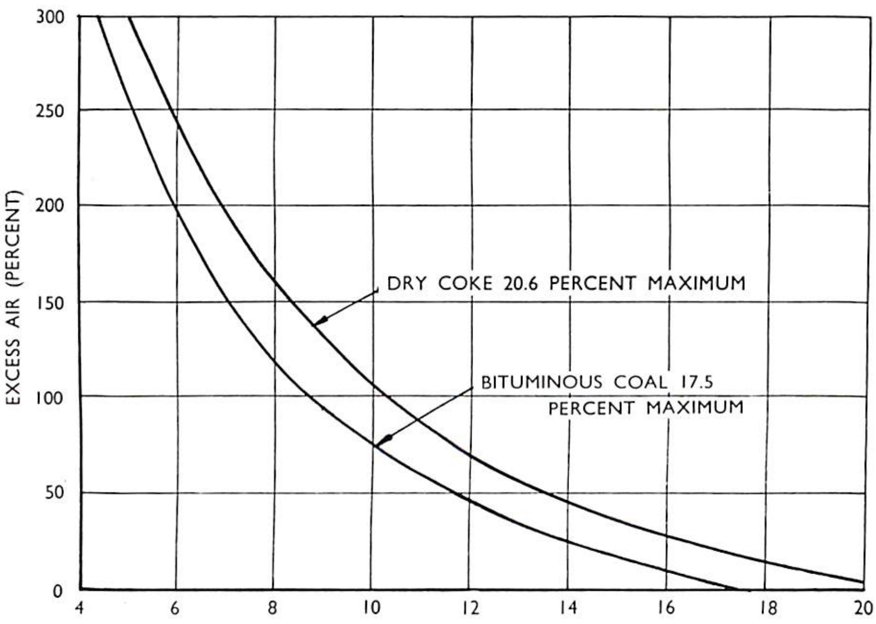



Fig. 4. The relationship between the percentage of carbon dioxide in the waste gases and the amount of excess air.

Comparing hand with mechanical-firing on two similar plants operating under the same load with the same grade of coal, mechanical-firing has the advantages which arise from the fact that coal can be fired and ash removed with the fire door closed. This avoids the inrush of cool air (in excess of that needed for combustion) which occurs each time the furnace is fired or cleaned by hand. Such air, mixing with the hot products of combustion, lowers the amount of heat transmitted from them to the water, and thus

increases the amount of heat carried away to the chimney. This advantage is lost if the fires burn thin at the back and excess air is thus allowed to enter the furnace. The installation of a mechanical stoker cannot, therefore, of itself produce an improvement in thermal efficiency, and if it is not intelligently controlled the thermal efficiency of a boiler may be lower than with hand-firing under comparable conditions.

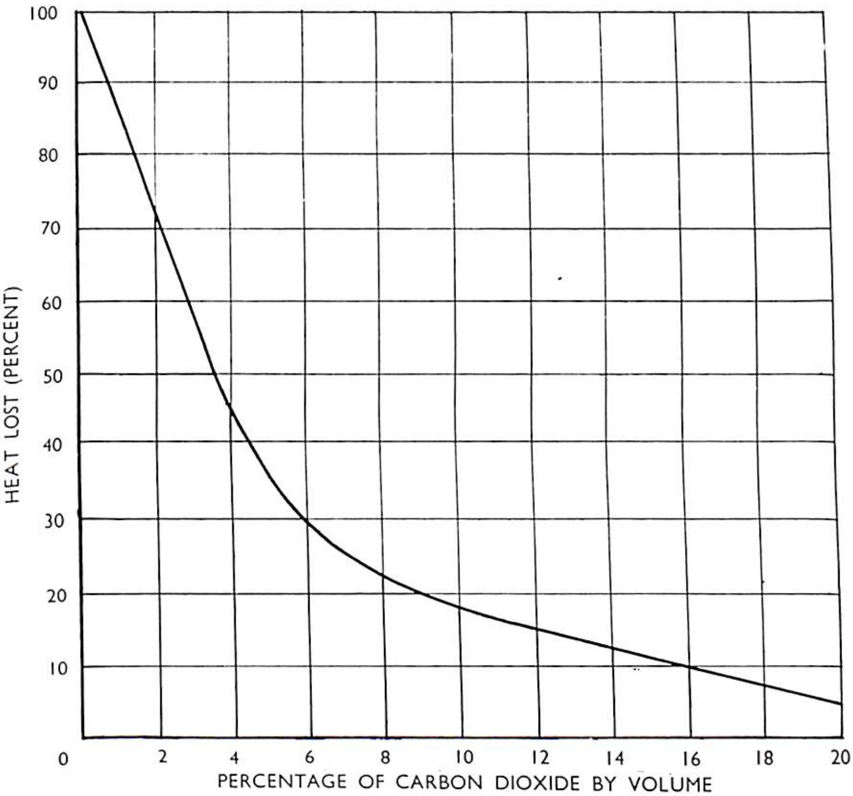



Fig. 5. The approximate relationship between the percentage of carbon dioxide in the waste gases (due to changing amounts of excess air) and the loss of heat expressed as a percentage of that available in the coal fired. Temperature of waste gases entering the chimney 500° F.
*Example:* When the $CO_2$ content is 6 per cent, the loss of heat is about 30 per cent.

The adverse effect of excess air on the performance of Lancashire boilers is not due solely to the cooling effect but also to the fact that the temperature of the gases leaving a boiler rises when the quantity of excess air is increased. This rise in temperature for a Lancashire boiler without an economiser is about 17 degrees Fahrenheit (° F.), for an increase of 10 per cent in the amount of excess air, and 15° F. for a Lancashire boiler with an economiser. The corresponding drops in thermal efficiencies are 2 per cent and 1.5 per cent, respectively.

When coal is burned completely in air the principal products are carbon dioxide ($CO_2$) and water vapour ($H_2O$), and as coal consists principally of carbon which, when burned, combines with oxygen from the air to form carbon dioxide, the percentage of carbon dioxide in the flue gases has become a measure of combustion efficiency. When coal is burned completely with the theoretically correct amount of air, the percentage of carbon dioxide in the waste gases varies with the composition of the coal; it is about 17.5 per cent with bituminous coals, about 19.25 per cent with anthracite, and about 20.6 per cent with dry coke. For Lancashire boilers with mechanical stokers and bituminous coal a good figure is from about 12 to 14 per cent, provided there is no smoke.

The variation in the percentage of carbon dioxide in flue gases with the amount of air in excess of that theoretically required for complete combustion is indicated in fig. 4. The heat wasted when the carbon dioxide content of flue gases is less than it could be, is indicated in fig. 5.

Comparisons of hand-firing with mechanical-firing practice have shown that the average increase in carbon dioxide in flue gases which may be obtained by mechanical stoking and controls, may be taken to be not less than 3 per cent (an increase of from, say, 9 to 12 per cent). The coal saving effected by the mechanical-firing of Lancashire boilers equipped with economisers is about 10 per cent.

**The Claims for Mechanical-Firing.**

The advantages claimed for mechanical-firing are as follows:—

(1) With hand firing a fireman may be placing his coal well at the start of a shift and operating at maximum efficiency, using the least possible amount of coal to generate the steam required. Later, however, as he tires, his placing of fresh coal may not be as good and more is fired to meet the same demand, thus reducing the thermal efficiency of the plant. A mechanical stoker fires steadily and consistently all the time, and operating conditions are greatly improved. The heavy work of "cleaning out" by hand is also avoided. It is, however, necessary to use intelligence and skill in the operation of mechanical equipment to obtain the desired results.

(2) The output of steam from a Lancashire boiler may be increased by mechanical-firing (see Table I).

(3) As coal becomes poorer in quality the advantage in favour of mechanical-firing decreases until a point is reached where coal cannot be fired mechanically and hand-firing has to be used. Mechanical stoking thus tends to restrict the number of grades of coal which can be fired. This does not apply to hand-firing, in which, with suitable draught conditions and one or two minor adjustments, almost any class of coal can be burned. Thus a medium caking coal of a certain size range is preferred for use with coking stokers and similarly sprinklers perform best with graded coals. The choice of type of mechanical stoker for a given boiler thus turns upon the grade of coal which it is desired to burn.

(4) With hand-firing the operator works to the steam pressure gauge, and as the pressure falls he increases his rate of firing, the aim being to keep up the working pressure. His standing as a stoker turns upon his ability to maintain pressure and not upon the quantity of coal he uses in doing this. On the other hand, mechanical stokers may be operated automatically by controls through which the quantities of coal and air are adjusted to keep the working pressure reasonably constant with changes in the demand for steam.

(5) With mechanical stokers, coal is fed on to the grate in a steady stream according to the steam demand. A continuous supply of overfire air is therefore required to burn the smoke. With hand-firing, at say 10-minute intervals, smoke is evolved only for the first 3 or 4 minutes, smokeless combustion and the highest efficiency being maintained only if the overfire air is adjusted at the beginning and end of this period, which is seldom the case. Furthermore, if the amount of overfire air is not increased for the burning of the smoke formed during this period, the efficiency of the plant may be lowered by 5 to 10 per cent.

These advantages may be summarised thus:—

(i) The work of the boiler operator is less arduous and more interesting.

(ii) A saving of coal of not less than 10 per cent is achieved for the same duty compared with hand-firing, when operating with the minimum excess air.

(iii) A greater output can be obtained from the boiler while operating at its maximum efficiency.

(iv) Automatic controls may be installed to help in maintaining a constant steam pressure.

(v) Loss of efficiency due to smoke is much more easily avoided.

# CHAPTER I

## COMMERCIAL CLASSIFICATION OF COALS

The differing properties of coals make it impossible to predict how a coal from any source will behave when burned upon a grate without a knowledge of its composition and some experience in its use. When the National Coal Board was formed there was no British standard for the commercial classification of coals, and until recently only the crudest descriptions were employed for industrial purposes.

More than half the total output of coal is used to raise steam, and it is possible to use almost every kind and size of coal for this purpose, if the equipment in which it is burned is appropriately designed. Hence, if a coal is to be used to the best advantage its behaviour when burning must be taken into account when choosing the equipment in which it is to be used, or, alternatively, knowing what coals a given plant has been designed to use with the highest efficiency, a coal within this range should be used with it. A system of classifying coal for commercial use is therefore essential if the best possible use is to be made of the coal reserves of this country.

**Classification by Rank.**

The two properties of a coal which it is essential to know for every purpose, are:—

(i) the proportion of volatile matter in it; that is, the quantity of gaseous and tarry matter which is driven off when it is heated.

(ii) the extent to which a coal cakes when it is heated.

These properties are measured under standard conditions to allow comparisons to be made, and the results are used by the National Coal Board to define the quality or rank of a coal, as indicated in Table III.

Apart from the clearly defined groups of coal known as anthracites and dry steam coals, and the very broad descriptive titles, coking and gas coals, there has been previously no common description of quality. Code numbers are used in this commercial classification instead of names for the different classes. This division of coals does not indicate their actual behaviour when burned, as there are other properties besides rank which help to decide the use to which a coal can be put most effectively; and size and ash content may be equally important. It is thus necessary to relate the performance of a coal when burned in different types and designs of combustion equipment with this code. This is done in practice by users when they decide, by trial and error, what grade or grades of coal are most suited to their needs.

Table III

A Classification of British Coals

| | Code number | Properties used to define rank: Volatile (dry ash free) % | Properties used to define rank: Coking property | Some other properties associated with rank: Calorific value (dry mineral matter free) | Carbon (dry mineral matter free) % | Hydrogen (dry mineral matter free) % | Inherent moisture % |
|---|---|---|---|---|---|---|---|
| Anthracite* .. .. | 100a | 4.5–6.5 | Non-caking .. .. .. | 15,250–15,550 | 93.0–94.5 | 2.8–3.35 | 1.5–3.0 |
| | 100b | 6.6–9.5 | Non-caking .. .. .. | 15,250–15,600 | 92.0–93.0 | 3.35–3.9 | 1.5–3.0 |
| Low-volatile steam coals | 201a | 9.6–12.0 | Non-caking .. .. .. | 15,600–15,750 | 91.0–93.0 | 3.9–4.2 | 0.7–1.5 |
| | 201b | 12.1–14.0 | Non-caking .. .. .. | | | | |
| | 202 | 14.1–15.5 | Weakly caking .. .. .. | 15,600–15,800 | 91.0–92.5 | 4.2–4.5 | 0.7–1.2 |
| | 203 | 15.6–17.5 | Medium caking .. .. .. | 15,600–15,800 | 90.0–92.0 | 4.3–4.8 | 0.7–1.2 |
| | 204 | 17.6–20.0 | Strongly caking .. .. .. | 15,200–15,950 | 89.0–92.5 | 3.7–4.6 | 1.0–3.0 |
| Scottish | 206 | 9.6–20.0 | Non-caking or weakly caking .. | | | | |
| Medium-volatile coals | | | | | | | |
| Scottish | 300 | 20.1–30.0 | Non-caking to medium caking .. | 15,300–15,900 | 85.5–90.5 | 4.6–5.2 | 1.0–2.5 |
| | 301 | 20.1–30.0 | Very strongly caking .. .. | 15,600–15,900 | 88.5 91.0 | 4.6 5.3 | 0.6–2.0 |
| High-volatile coals .. | 401a | 30.1–33.0 | Very strongly caking .. .. | 15,600–15,900 | 88.5 91.0 | 4.6–5.3 | 0.6–2.0 |
| | 401b | 33.1–37.0 | Very strongly caking .. .. | | | | |
| | 402 | Over 37.0 | Very strongly caking .. .. | 15,200–15,800 | 85.0 88.9 | 5.1–5.6 | 0.6–2.5 |
| | 501a | 30.1–33.0 | Strongly caking .. .. .. | | | | |
| | 501b | 33.1–37.0 | Strongly caking .. .. .. | 15,000–15,600 | 84.0–87.0 | 5.2–5.7 | 1.1–4.0 |
| | 502 | Over 37.0 | Strongly caking .. .. .. | | | | |
| | 601 | 30.1–37.0 | Medium caking .. .. .. | 14,800–15,400 | 83.0–86.5 | 5.2–5.7 | 1.6–5.5 |
| | 602 | Over 37.0 | Medium caking .. .. .. | | | | |
| | 701 | 30.1–37.0 | Weakly caking .. .. .. | 14,600–15,200 | 82.5 86.0 | 5.2–5.6 | 2.1–10.0 |
| | 702 | Over 37.0 | Weakly caking .. .. .. | | | | |
| | 801 | 30.1–37.0 | Very weakly caking .. .. | | | | |
| | 802 | Over 37.0 | Very weakly caking .. .. | 14,100–15,000 | 80.0–85.0 | 5.0–5.7 | 3.6–13.5 |
| | 901 | 30.1–37.0 | Non-caking .. .. .. | | | | |
| | 902 | Over 37.0 | Non-caking .. .. .. | | | | |

* Closer definition of the sub-divisions of the main anthracite group is sometimes necessary, and this is done on the basis of the hydrogen content of the coal substance.

TABLE IV—AN ANALYSIS OF THE 1948 OUTPUT IN TERMS OF THE RANK OF THE COAL (% OF OUTPUT OF EACH DIVISION)

| National Coal Board Divisions | 100(a) | 100(b) | 201 | 202 | 203/4 | 206 | 300 | 301 401* | 400 | 500 | 600 | 700 | 800 | 900 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scottish.. .. .. .. | — | 1.9 | — | — | — | 1.5 | 3.5 | — | — | 2.5 | 6.7 | 13.4 | 26.5 | 44.0 | 100.0 |
| Northern .. .. .. | — | — | — | — | — | — | — | 19.2 | 21.9 | 32.8 | 8.0 | 15.5 | 2.6 | — | 100.0 |
| North Eastern .. .. | — | — | — | — | — | — | — | — | 2.7 | 36.5 | 29.5 | 21.6 | 9.3 | 0.4 | 100.0 |
| North Western .. .. | — | — | — | — | — | — | — | — | 1.3 | 21.3 | 30.4 | 27.7 | 18.5 | 0.8 | 100.0 |
| East Midlands .. .. | — | — | — | — | — | — | — | — | 0.7 | 5.7 | 11.1 | 21.8 | 35.7 | 25.0 | 100.0 |
| West Midlands .. .. | — | — | — | — | — | — | — | — | 1.5 | 4.3 | 10.4 | 17.3 | 42.9 | 23.6 | 100.0 |
| South Western.. .. .. | 4.9 | 7.5 | 13.0 | 12.1 | 22.1 | — | — | 24.8 | 8.2 | 2.3 | 2.1 | 2.4 | 0.5 | 0.1 | 100.0 |
| Kent .. .. .. .. | — | — | — | — | 34.8 | — | — | 43.6 | 21.6 | — | — | — | — | — | 100.0 |
| Great Britain .. .. .. | 0.7 | 1.2 | 1.7 | 1.6 | 3.2 | 0.2 | 0.4 | 7.5 | 6.6 | 17.6 | 13.8 | 16.8 | 17.0 | 11.7 | 100.0 |

* Durham only.

Table IV is a statement of the percentage of the total output of coal of the various ranks in each Division of the N.C.B. (the figures are for 1948), and is of interest because it shows which grades of coal tend to predominate in different parts of the country.

**Other Properties Associated with Rank.**

Any assessment of the relative values of coals must have regard to the quantity of heat they contain, that is, to their calorific values. This is usually expressed in British Thermal Units per pound (B.Th.U. per lb.), one B.Th.U. being the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

*The gross calorific value* is the number of British Thermal Units liberated when one pound of coal is completely burned in oxygen saturated with water vapour, the final products at 60° F. being carbon dioxide, sulphur dioxide, nitrogen and *liquid water*. The gross calorific value is usually determined in a bomb calorimeter.

*The net calorific value* is the number of British Thermal Units liberated when one pound of coal is completely burned in oxygen saturated with water vapour, the final products at 60° F. being carbon dioxide, sulphur dioxide, nitrogen and *water vapour*. The net calorific value is thus lower than the gross by the amount of heat required to vaporise the water in the coal and also that formed in its combustion.

*Carbon* (or coke) is the solid left when the volatile matters have been expelled by heat.

*Hydrogen* is a gas which occurs in coal principally in combination with carbon as hydrocarbons, and is part of the volatile matter.

## Table V—Standard Size Groups for Graded Coals

| Name of group | Typical screen size (in round hole) | Permitted range of screen apertures (in round hole)* | | Criteria of undersize—neither to exceed | |
|---|---|---|---|---|---|
| | | Upper limit | Lower limit | A† | B† |
| Large cobbles | $6 \times 3$ | 6–8 | 3–5 | — | — |
| Cobbles | $4 \times 2$ | 4–5 | 2–3 | — | — |
| Trebles | $3 \times 2$ | $2\frac{1}{2}$–$3\frac{1}{2}$ | $1\frac{1}{2}$–2 | 15% through $1\frac{1}{4}$ in. square | 2% through $\frac{1}{4}$ in. square |
| Doubles | $2 \times 1$ | $1\frac{3}{4}$–$2\frac{1}{4}$ | 1–$1\frac{1}{2}$ | 25% through $\frac{7}{8}$ in. square | 3% through $\frac{3}{16}$ in. square |
| Singles | $1 \times \frac{1}{2}$ | 1–$1\frac{1}{2}$ | $\frac{1}{2}$–1 | 20% through $\frac{3}{8}$ in. square | 3% through $\frac{1}{8}$ in. square |
| Peas | $\frac{1}{2} \times \frac{1}{4}$ | $\frac{1}{2}$–$\frac{3}{4}$ | $\frac{1}{4}$–$\frac{1}{2}$ | 15% through $\frac{3}{16}$ in. square | 3% through $\frac{1}{16}$ in. square |
| Grains | $\frac{1}{4} \times \frac{1}{8}$ | $\frac{1}{4}$–$\frac{7}{16}$ | $\frac{1}{8}$–$\frac{1}{4}$ | 25% through $\frac{1}{8}$ in. square | 3% through $\frac{1}{32}$ in. square |

* Appropriate equivalent square apertures which may be used.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| In round hole | 8 | 6 | 5 | 4 | $3\frac{1}{2}$ | 3 | $2\frac{1}{2}$ | $2\frac{1}{4}$ | 2 | $1\frac{3}{4}$ | $1\frac{1}{2}$ | 1 | $\frac{3}{4}$ | $\frac{1}{2}$ | $\frac{7}{16}$ | $\frac{1}{4}$ | $\frac{1}{8}$ |
| In square hole | 7 | $5\frac{1}{4}$ | $4\frac{1}{4}$ | $3\frac{1}{2}$ | 3 | $2\frac{5}{8}$ | $2\frac{1}{8}$ | $1\frac{7}{8}$ | $1\frac{3}{4}$ | $1\frac{1}{2}$ | $1\frac{1}{4}$ | $\frac{7}{8}$ | $\frac{5}{8}$ | $\frac{3}{8}$ | $\frac{3}{8}$ | $\frac{1}{4}$ | $\frac{1}{8}$ |

† These square meshes refer to those defined in B.S 410 and are to be used for determination of sieve analyses as required by B.S. 1293.
*Note.*—The Committee anticipates that the process of evolution of screen sizes will bring them as near as practicable towards the typical sizes.

## Table VI Description of Smalls

| Treatment<br>Size and shape of aperture<br>Fines content in class | |
|---|---|
| Classes for fines content | Described as |
| 0–15% through $\frac{1}{8}$-in. square mesh | 15 |
| 15–25% | 25 |
| 25–38% | 38 |
| 38–55% | 55 |
| 55–75% | 75 |
| 75–100% | 100 |

## Table VII

| Rank | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 |
|---|---|---|---|---|---|---|---|---|---|
| Size: Large | | | | | | | | | |
| Unscreened | | | | | | | | | |
| Graded coal | | | | | | | | | |
| Washed smalls | | | | | | | | | |
| Untreated smalls | | | | | | | | | |
| Others | | | | | | | | | |

*Inherent moisture.* This is the moisture in the pores of coal which cannot be removed by mechanical means. The amount varies with rank.

Other properties which determine the use to which a coal can be put arise from mineral matter associated with coal, and of these we are concerned with the quantity and nature of the *ash* produced when the coal is burned, and the quantity of *free moisture*, that is, of moisture which can be removed by draining or by centrifugal force.

**Classification by Size.**

The National Coal Board has adopted the recommendations made by the Coal Grading Committee of the British Coal Owners' Research Association in 1946. Size is defined by upper and lower screen sizes (Table V) and by the percentage of under size and fines content* (Table VI).

All coals have rank and size. We need therefore to specify both these properties in order to classify a coal for commercial use, and when we do this each coal can be placed within the classification set out in Table VII.

**Properties Affecting Use of Coals for Steam Raising.**

All coals marketed in this country can be used efficiently for steam raising provided the design of the plant and the method of operating it are appropriate.

*Rank and calorific value.* In general, the lower the rank of a coal the lower the calorific value of the coal substance. This has two main effects: there is a lower heat input to the furnace per pound of coal fired, assuming the percentage of ash in the coal is the same or that the calorific value is calculated, as is usual, on the ash-free substance, and a lower intensity of heat is produced.

*Volatiles and burnability.* The lower the volatile content of a coal the more difficult it becomes to promote and maintain combustion. Furnaces designed to burn low volatile (high rank) coals therefore have arches built of refractory brick to absorb and reflect sufficient heat back on to the fuel bed to ignite incoming coal and maintain combustion. High volatile coals burn more easily, and sufficiently rapid burning is obtained in small and medium-sized installations with natural draught.

*Size.* Large coal is not suitable for firing shell boilers. When it has to be used it is first broken and then fired by hand. Mechanical stokers are designed to fire a certain range of sizes, and improved designs of grate and controls have made higher and more satisfactory rates of burning possible when using smalls. Grit carry-over becomes excessive, however, when the proportion of fines is too high. Difficulties may also arise with coal handling plant, and segregation may produce an uneven fuel bed.

---

**Note.*—Any particular smalls should be placed in the class of fines for which the upper percentage is only exceeded once in 20 times. For example, if the fines content of the individual consignments frequently exceeds 25% and 19 times out of 20 does not exceed 38%, then the smalls lie in the 38% class.

*Moisture.* Inherent moisture increases with decrease in rank, and coals of the lowest rank may contain from 15 to 16 per cent. Free moisture is acquired when coal is washed, and is that moisture which remains after normal draining. Free moisture within certain limits improves the fuel bed by lowering its resistance to the passage of air, and in a way not clearly understood, stimulates combustion.

*Ash.* The nature of the ash is also important as it bears directly on the formation of clinker, and the heat loss with a given coal due to unburned carbon and sensible heat in ash increases as the percentage of ash increases.

# CHAPTER II

# THE BURNING OF COAL

**Primary and Secondary Supplies of Air.**

The object in burning coal is to obtain and usefully employ the heat it contains. When coal is burned in an even bed upon a grate and air is passed upwards through it, each fresh charge is heated in turn by the hot gases which rise from the lower part of the bed. It is thus dried and gradually heated up. Decomposition then begins, and volatile matter rises into the space above the bed, until finally a residue, coke, is left on the grate. This sequence proceeds from the grate upwards until all the coal is converted into coke. The volatile matter burns in the space above the bed, and the coke or carbon is burned on the grate. Two distinct supplies of air are thus required, one below the grate to burn the coke, which may be conveniently described as the *primary supply*; and another above the grate (over the fire) to burn gases and tarry vapours—the *secondary supply*.

There is no practical difference between the burning of coal and coke on a stationary grate, apart from the distillation and burning of volatile matter, as coal is converted layer by layer into coke. The relative amounts of the primary and secondary supplies of air needed to burn a given coal thus vary with its volatile content and with some coals, notably from the S. Wales coalfield, a secondary supply of air may be unnecessary.

**The Composition of Air.**

The supply of oxygen for combustion is obtained from air. The supply of air is thus equally as important as the supply of fuel. The average composition of air by volume may be taken for this purpose to be 79 per cent nitrogen and 21 per cent oxygen; and by weight, 77 per cent nitrogen and 23 per cent oxygen. Nitrogen does not burn but passes through the fuel to the chimney unchanged, except, of course, in temperature.

**Ignition.**

Coal must be ignited before it can burn. Ignition is effected by raising it to the temperature at which the rate of burning provides the heat essential for the process to continue. Burning does not therefore appear below this temperature, which varies with different fuels and with different sizes of the same coal. Incidentally, the ignition temperatures of hydrocarbon gases and tarry vapours are higher than that of the residue left on the grate.

A fuel is considered to have reached its ignition temperature if ignition spreads over its surface when a flame is brought into contact with it. The

time required for a fuel to reach this temperature is greater the lower the temperature of its surroundings. This being so, the temperature over a fuel bed must be maintained at not less than the highest ignition temperature of the combustible gases rising from it, if they are to be burned. Heat-retaining arches of refractories are often built over grates at the front, and are continued a sufficient distance over the grates to achieve and maintain ignition conditions with the coal to be used.

Coals of high rank, that is coals with high fixed carbon and a low volatile content, ignite less easily than low rank coals. Anthracites have the highest fixed carbon content and their ignition is effected and maintained with the aid of relatively long refractory arches.

The speed at which coal will burn increases more rapidly with the air rate than does the rate of ignition. The maximum rate of burning is thus limited by the ignition rate. Too great a supply of air at the front of a grate retards ignition by reducing the temperature of the surfaces over which it passes and also that of the combustible gases. Air should not therefore be allowed to pass into a fuel bed until the fuel has been ignited. The rate at which any coal will burn is thus limited also by the conditions under which it is burned and is not dependent solely upon quantity of air.

Free moisture in coal has to be driven off before ignition can occur. Small coal ignites more readily than large coal, and there is usually a characteristic size with any coal at which ignition is most rapid. Ash does not appear to retard ignition in quantities up to about 35 per cent.

**Burning Coal.**

The important combustible constituents of coal are carbon and hydrogen. Sulphur occurs to a small extent but its value as a combustible may be neglected. Besides these constituents there are also oxygen and nitrogen and small quantities of mineral substances which yield ash when the coal is burned. It must not be thought from this statement, however, that these elements exist separately in coal. This may be so to a very limited degree, but the actual composition is extremely complicated. Hydrogen, for example, is in combination with carbon, with which it forms a large number of different chemical compounds called hydrocarbons.

The burning of coal is therefore a complex progression of physical and chemical changes, in the course of which carbon, hydrogen and sulphur combine with oxygen from air with the liberation of heat. The amount of air required for the burning of each constituent is not the same, so that the quantity of air needed to burn a pound of coal depends upon its chemical composition, or put in another form, upon its heat content, and with industrial coals may vary from about 9 to 12 pounds. The amount of air required to burn any coal as calculated from its chemical composition (the theoretical requirement) is not, however, sufficient in practice to ensure complete combustion. This quantity is only an approximate guide to the actual need, as from 30 to 40 per cent in excess of this quantity is necessary to ensure complete combustion in shell boilers.

The thermal efficiency of a steam boiler is measured by the actual amount of heat transferred to the water and steam per pound of coal used, and is

expressed relative to the total heat in one pound of the coal. If, for example, 70 per cent of this amount is so transferred, the thermal efficiency of the boiler is said to be 70 per cent. The efficient operation of steam boilers thus requires coal to be burned as completely as possible with the right amount of excess air, that is, of air which is necessary over and above the theoretical amount, if the maximum possible efficiency is to be obtained. Any further quantity of excess air beyond this amount serves only to lower the temperature of the combustion gases, carry away heat to the chimney, and lower the efficiency of the plant.

*Each grade of coal has a characteristic ignition rate which determines the maximum rate of burning.* This has to be found by trial and error. So also has the quantity of air required to ensure complete combustion, and the rate at which the air must be supplied to secure the maximum rate of heat release within a given furnace. The attainment of maximum combustion efficiency with any coal thus depends upon the design of the plant and the skill of the operator.

Tests have indicated that the combustion efficiency, and hence the amount of heat which can be transferred to the water, in a Lancashire boiler reaches a maximum when between 30 and 40 per cent of excess air is provided. The quantity of heat transferred falls off more quickly due to incomplete combustion, as the percentage of excess air is reduced, than when the percentage is raised from the optimum figure. A reduction in excess air from 40 to less than 20 per cent has been found to produce the same drop in heat transfer as increasing the amount of excess air to 80 per cent.

**Burning Carbon.**

In burning coal, we are concerned principally with the combination of carbon with oxygen from air to form carbon monoxide and then of carbon monoxide with more oxygen to produce carbon dioxide.

Combustion of carbon thus occurs in two clearly defined stages:—

(1) Carbon *plus* oxygen forms carbon monoxide, with the liberation of 4,350 B.Th.U. per pound consumed.

(2) Carbon monoxide *plus* oxygen forms carbon dioxide with the liberation of a further 10,150 B.Th.U.

The major part of the total heat, 14,500 B.Th.U. per pound of carbon, is thus released in the second stage, and this occurs out of contact with the surface of the fuel.

In the burning of carbon in any form, the first product is carbon monoxide, and, after ignition, this reaction is maintained by the heat it itself produces. The second stage, the burning of the monoxide to carbon dioxide, however, is different, in that no further heat is required either to start or to maintain it. Given the necessary supply of air, this reaction spreads through the mixture at an ever-increasing rate until arrested by lack of carbon monoxide.

When air passes upwards through a bed of incandescent carbon (coke), it is burned to carbon monoxide at the exposed surfaces, and this gas passing into the air stream is burned to carbon dioxide. If this does not occur in the spaces within the bed it occurs in the space above it. The pattern of

heat release with a given air rate thus depends to some extent upon the packing of the fuel in the bed, and thus upon the size range of the coal.

*Carbon in any fuel bed burns in a steady stream of air at a rate which shows remarkably little falling off until* 90 *to* 95 *per cent of it has been consumed.*

When a bed of coal on a stationary grate is ignited at the top, ignition travels downwards towards the grate. During this period the air stream is charged with tarry vapours, gaseous hydrocarbons and moisture. The burning of these gases and of the residual coke then occurs together in proportions which depend on the system of firing, and on whether the grate is stationary or moving.

**Overfeed, Underfeed and Crossfeed Fuel Beds.**

A bed in which the coal and air move in opposite directions, as with a stationary grate, is called an overfeed fuel bed, in contrast to one in which the fuel and air move in the same direction—an underfeed fuel bed, which occurs to some extent in underfeed stokers. In a crossfeed fuel bed the fuel moves in a direction normal to the flow of air, as with a travelling or moving grate when fuel is fed at the front end. The more intimately fuel and air are mixed the higher the rate of burning and the greater the intensity of combustion. The most intense combustion thus occurs with an overfeed fuel bed. In practice all fuel beds exhibit these characteristics in some degree, so that when we say that a particular furnace has an overfeed fuel bed, we mean that this characteristic predominates.

**Burning Hydrocarbons (Volatiles).**

When coal is spread over a bed of burning coke, the volatile matter in the coal—frequently over 30 per cent of its weight—is distilled from it in

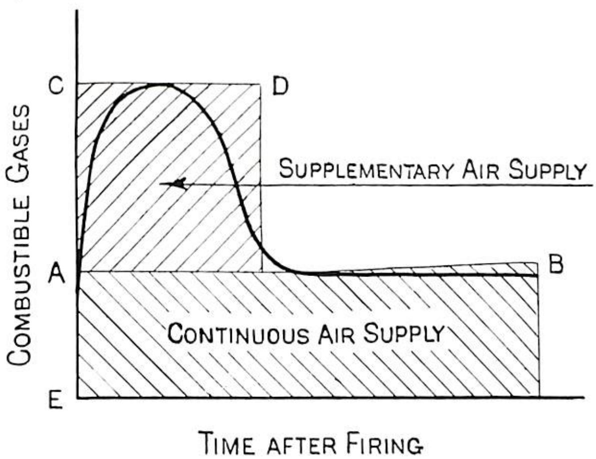



Fig. 6. The rate of evolution of combustible gases (diagrammatic) with a stationary grate and hand-firing.

the form of combustible tarry vapours and hydrocarbon gases. If these vapours and gases are not mixed with sufficient air at a temperature at which they will ignite, they pass up the chimney unburned, and if they are subjected

to a high temperature without first being mixed with air they pass to the chimney as black "sooty" smoke. Thus, if these gases and tarry vapours are to be burned, and the emission of smoke is to be avoided, sufficient air must be provided over the grate to effect their combustion.

When hydrogen burns it combines with oxygen to form water vapour (steam); when hydrocarbons burn in air the carbon in their constitution combines with oxygen to form carbon dioxide, and the hydrogen combines with oxygen to form water vapour (steam). That is, the products obtained by burning carbon and hydrogen completely, or any compounds of carbon and hydrogen (hydrocarbons), are simply carbon dioxide ($CO_2$) and water vapour ($H_2O$).

The rate at which combustible gases leave a fuel bed during a firing cycle with hand-firing on a stationary grate varies, as the volatile matter is driven off fairly quickly. A typical example of this is shown in fig. 6. A supplementary or secondary supply of air is thus needed during the distillation period if the emission of black smoke is to be avoided (from C to D in fig. 6), but this should not raise the excess air beyond the limit of 40 per cent if the highest heat transfer is to be obtained.

**Intensity of Burning.**

There are therefore two principal stages in the burning of coal on a grate: ignition, and burning out. When coal is fed on to the top of the burning bed with air passing upwards through it, it is ignited at the surface and burns downwards. The volatiles then burn over the bed with a secondary supply of air, and the charge is finally burned out in a stream of air from under the grate. In these circumstances, ignition travels downwards and when this reaches the grate the coke burns out from the bottom of the bed upwards.

With high rank, high carbon, low volatile coals the ignition stage is relatively short, and the burning out stage long, but with low rank coals so much gasification takes place during the ignition period that only a relatively small amount of carbon remains to be gasified during burning out. In these circumstances with high air rates the two stages may occur together. The highest intensity of combustion occurs under these conditions, and the greater this intensity the greater is the amount of heat transferred by radiation to the furnace crown. When this occurs, caking is retarded and often completely prevented.

The average temperature in shell boiler furnaces varies from about 1,450° F. up to a maximum of about 3,000° F.

**Net Calorific Value and the Theoretical Amount of Air Required for Complete Combustion.**

Coal is sold on its gross calorific value. This quantity of heat is, however, completely available only if the steam formed during combustion is condensed to liquid water. The waste gas temperatures in boiler practice are, however, too high for steam to condense; it is therefore more helpful to use the net calorific value, which allows for this unavoidable loss.

**When carbon or hydrogen in any form is burned with the theoretical amount of air, the heat content per cubic foot of the combustion gases is practically the same, namely 100 B.Th.U. per cu. ft. at standard atmospheric pressure and 32° F.** Coal consists in the main of varying proportions of carbon and hydrogen, and the presence of sulphur and other compounds does not appear to affect this relationship.

**A bituminous coal, with a net calorific value of 13,000 B.Th.U. per lb. with the theoretical amount of air, thus yields 130 cu.ft. of combustion gases with a heat content of 100 B.Th.U. per cu. ft. at standard atmospheric pressure and 32° F.**

**The calculation of the net calorific value of coal.** The net calorific value of a coal can be calculated from the gross value using the equations in Table VIII. These are considered accurate to within ± 1 per cent.

TABLE VIII

GROSS AND NET CALORIFIC VALUES

| Fuel | Calorific value gross, B.Th.U. per lb. $C_G$ | Calorific value net, B.Th.U. per lb. $C_N$ |
|---|---|---|
| Bituminous coal .. .. .. .. .. | 11,000–16,000 | $0.954C_G + 200$ |
| Anthracite .. .. .. .. .. .. | 14,500–15,000 | $C_G - 320$ |
| High temperature coke .. .. .. .. | 12,000–13,500 | $C_G - 70$ |

**The Total Quantity of Air Required.**

**Approximately 10 lb. of air is required for the complete combustion of any coal for every 10,000 B.Th.U. (net C.V.) with 33 per cent of excess air.****

The air required by a given boiler can thus be calculated by allowing 10 lb. of air for each 10,000 B.Th.U. (net) of the coal to be burned. Alternatively, the heat which must be transferred to the water in a boiler at the operating pressure with maximum output (M.C.R.) may be calculated with the aid of steam tables. This figure (in B.Th.U.), when corrected to take into account the average or anticipated efficiency of the plant, divided by 1,000 gives the weight of air required in pounds. A margin may be added to cover extraordinary peak loads. The supply of air under the grate normally accounts for over 70 per cent of this amount when burning bituminous coals, depending on the percentage of fixed carbon in the coal.

**The practical significance of these facts is that if we are to obtain the same rate of heat release on a grate with a coal of net calorific value 9,000 B.Th.U. per lb. as with a coal of 12,000 B.Th.U. per lb. net, one-third more of the lower quality coal will have to be burned in the same time. However, since the heat content of the combustible gases from both coals is the same per cubic foot, the same quantity of air will be required in each case.**

---

* It is useful to know that 1 lb. of air at standard atmospheric pressure and 32° F. occupies 12.39 cu. ft.

**Ash and Clinker.**

Ash is the residue which remains when the combustible constituents of coal or coke have been completely burned. When ash is melted the particles run together and the molten mass when cool is known as clinker.

Physically, the ash of coal is a complex mixture. It consists of mineral matter originally intimately mixed with the coal substance: inherent ash, the non-combustible part of the vegetable material from which the coal was formed: and extraneous material that occurs as partings, bands, and nodules of shale, bone, pyrite, or clay in coal seams.

The ash of coal is thus complex, both chemically and physically. The principal constituents as reported in a chemical analysis are silica and alumina and the fluxes, iron oxide, lime, magnesia, and sodium and potassium oxides. The action, however, upon heating, whether the ash remains a dry powder or melts to a fluid mass, depends not only on the amounts of the various constituents present, but also upon the relative amounts of each and the forms in which they are combined.

It is largely because of this lack of intimate mixing that it is impossible to predict the behaviour of ash from a coal when burned when given the ash fusion temperature, as determined in the laboratory. No part of the ash in a fuel bed has the same composition as a laboratory test sample, as the latter is a carefully blended average. It has been found:—

(1) that with coals from the same seam, clinker formation decreases with increase in fusion temperature, and increases with increase in ash content;

(2) that with coals from different seams, the relation between ash fusion temperature and clinker trouble may not be very clear;

(3) that clinker formation is determined as much by physical conditions as by chemical composition, depending, for example, on agitation of the fuel bed or on a local high temperature, and upon the distribution of the ash within the bed.

# CHAPTER III

# SYSTEMS OF FIRING

The output of steam from a given boiler varies with:—

(1) The ratio of the total heating surface to the effective grate area. This varies with the diameter of the boiler, as there are constructional and operational limits to the diameter of furnace tubes which can be used with a given diameter of boiler shell and to the length of grate relative to the length of the boiler.

(2) The calorific value of the coal used.

(3) The rate of heat release. This is not the same for all coals; with some it is impossible to obtain the standard Maximum Continuous Rating (M.C.R.) from shell boilers of normal design, as these coals cannot be effectively burned at the rate needed to obtain this. Hence Table I, which gives the maximum continuous ratings of Lancashire boilers for coals of different calorific values and for different systems of firing.

Shell boilers may be fired by hand or by mechanical means. The standard furnace equipment for hand-firing is shown in fig. 7, and a smoke eliminator door for hand-firing and natural draught in fig. 8.

There are three systems of hand-firing—spreading, coking and alternate side- or wing-firing.

**Spreader or Sprinkler Firing.**

A section through a fuel bed with spreader or sprinkler firing is shown in fig. 9. Coal is spread evenly and thinly over the fuel bed, a little coal being fired at a time, with short intervals between successive firings, so that the volatile matter may be ignited and not allowed to escape unburned as smoke to the chimney.

Heavy charges of coal take an appreciable time to ignite, and the heat may not in these circumstances be sufficiently intense to ignite the volatile matter which therefore passes as "black smoke" to the chimney.

The conditions and methods favourable to this system are:—

(1) Boiler working below maximum capacity.

(2) Good draught.

(3) Regular and uniform firing.

(4) Fires not allowed to burn too thin, coal being fired while there is sufficient fuel still burning to ignite the fresh coal and thus maintain a brilliant fire.

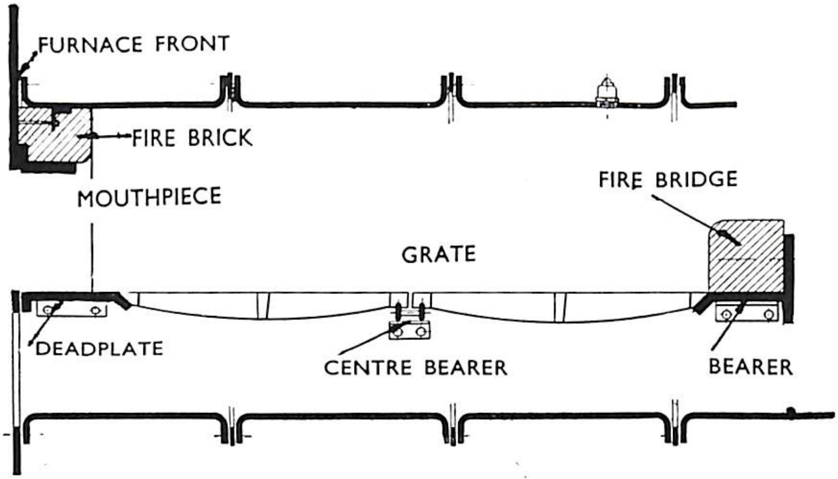



Fig. 7. Standard furnace equipment for hand-firing.
The firedoor is shown in fig. 8.

Wrought iron or steel **brackets** are bolted, riveted or welded to the furnace to carry the dead plate, bridge and bar bearers.

The **grate** provides a surface on which coal may be burned, so arranged that air supplied below it is effectively distributed to the burning fuel.

The ends of the grate bars, which rest on the deadplate, and the firebridge are suitably bevelled to allow for expansion, and are held in position by lips over the centre bearer.

Grates are given a slope of up to 4 inches from front to back to increase the combustion space above the fuel bed, the free space above the fuel bed, and the free space above the firebridge.

A **firebridge** is provided to prevent coal from being thrown over the back of the grate into the furnace tube, and to prevent air by-passing the grate at the back. It is built of firebrick, is 9 in. thick, and the distance from the top of the bridge to the crown of the flue varies from 11 to 15 in., depending on the diameter of the tube.

A **smoke eliminating door** with an opening of 32 square inches for continuous air, and 29 square inches for supplementary air.

A **furnace front** of wrought iron or steel plate fitted in the opening in the end plate, and firmly bolted in position.

A cast-iron **mouthpiece** bolted to the back of the front plate. The space at the back of the mouthpiece is filled with a firebrick liner to prevent the front and the boiler seams from becoming overheated.

A cast-iron **deadplate.** This is bolted to the furnace front and bevelled to suit the firebars. It should be about 12 in. deep from front to back for flat-ended boilers, and deep enough with dish-ended boilers to keep the ends of the firebars well away from the end ring-seam.

A **firebridge bearer** of cast iron bolted to brackets fixed in the furnace plate. The end of the bearer is bevelled to suit the firebars, and the centre bearer is arranged so that ashes cannot accumulate between the ends of the bars.

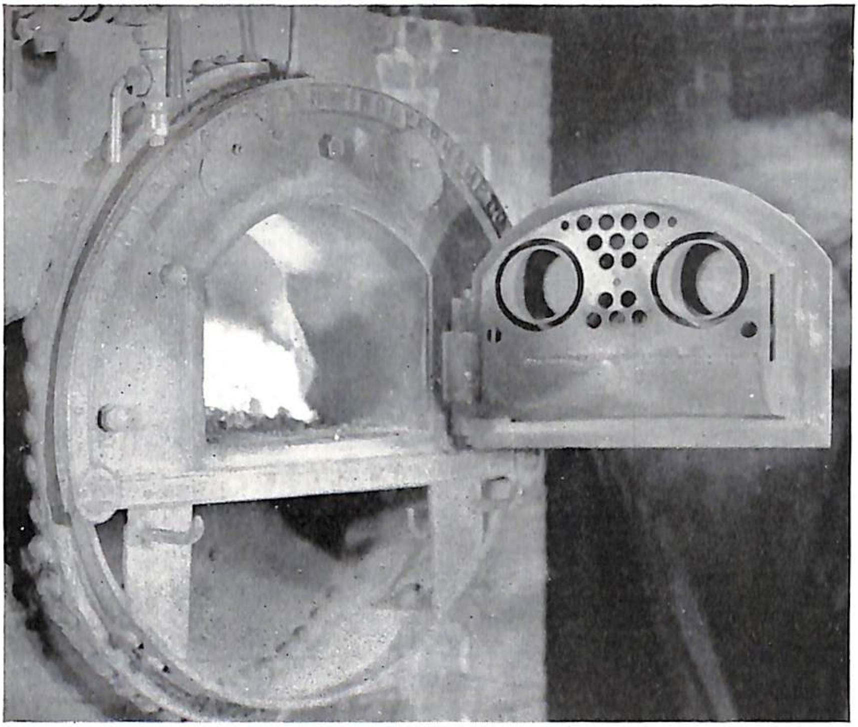


Fig. 8. F.R.S. smoke eliminator door for a hand-fired natural draught Lancashire boiler. This should be fitted as part of the standard furnace equipment.

**The Coking System.**

In the coking system fresh coal is not spread over the whole of the fire, but is piled on a plate through which air cannot pass—a dead plate—or on the front end of the bars (fig. 10). This heap becomes incandescent as the volatiles are driven off, and when it is partially coked it is pushed forward on to the grate. It is then thrust step by step along the grate at such a rate that when it reaches the fire-bridge combustion is complete. Hydrocarbons are distilled from the fresh coal on the dead plate, and in passing over the glowing fire on the rest of the grate they ignite and burn.

This is the most economical way to fire a boiler by hand. It requires more skill and more hard work than any other method, as it calls for the systematic use of a rake to keep the grate covered and prevent air leaks. It is also the most effective way to prevent smoke. Great care is needed, however, to keep the bars fully covered as the back of the grate cannot be seen over the heap of coal at the front.

**Alternate Side-Firing.**

It is good practice, with bituminous coals, to use the alternate side-firing method, that is, to throw coal to one side of the grate only throughout its length, say to the left-hand side at one firing, leaving the right-hand side

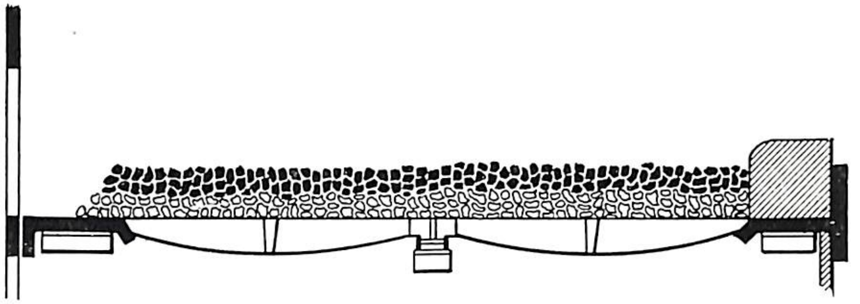


Fig. 9. A cross-section through a fuel bed with spreader and sprinkler firing on a stationary grate. The black fuel represents freshly-charged coal.

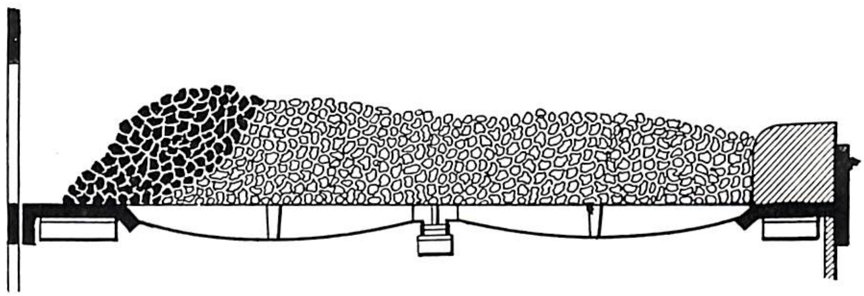


Fig. 10. A cross-section through the fuel bed fired on the coking system. The black fuel represents freshly-charged coal.

Fig. 11. A cross-section through a fuel bed with alternate side firing. The black fuel represents freshly-charged coal.

bright, and so on, as indicated in fig. 11. The coal as it is coked then tends to fall back into the centre, and the middle of the bed becomes a channel of incandescent coke which ignites the volatiles escaping from the fresh coal banked up at the sides.

The advantage of this method, compared with the coking system, is that there is less difficulty in keeping the back part of the grate covered, and air leaks through the fuel bed are not so likely to occur. The fuel on the grate

should be kept level except for the banking at the sides, and of sufficient thickness to prevent cold air passing through the centre of the grate. The method ensures that the sides of the furnace are fully covered and that there are no holes or channels in the fire at the sides, where the passage of cold air would be detrimental to the life of the furnace tube, as well as leading to waste of fuel.

Whatever method of hand-firing is adopted, bars should be kept well covered and the fire clean; the thickness of the bed should be not less than 4 to 5 inches and the two furnaces of a Lancashire boiler should be fired alternately, not at the same time. Holes are more likely to develop in thin fires, and when this happens excessive quantities of cold air pass through the bars, lowering the temperature of the gases and increasing the amount of coal to be fired for a given duty.

# CHAPTER IV

# THE SUPPLY OF AIR FOR COMBUSTION

## DRAUGHT

If the pressure of the gases at any point in the furnace or flues of a boiler system be reduced, other gases will flow to this point to equalise the pressure. If, therefore, the gases at the chimney are at a lower pressure than that of the atmosphere and the system is open to the atmosphere only at the furnace front, gases will flow to the chimney base under the pressure of the atmosphere. This difference in pressure which causes air and products of combustion to flow through flues is called draught. And there must be sufficient draught to overcome the resistance of the firebed, and of the internal surfaces of the whole system, if the requisite flow of air into the furnace is to be maintained.

### Natural and Artificial Draught.

The force which causes air to flow through a furnace is called natural draught when it is produced by a chimney and artificial draught when it is produced in any other way. The principal devices by which an artificial draught is produced are the steam-jet air injector and the fan.

The draught required for a given duty depends upon:—

(1) The rate of burning desired; the greater the rate the greater the draught required.

(2) The thickness of the fuel bed. The thicker the bed the greater the resistance to be overcome.

(3) The quality and size of coal used. When a coal is low in volatile matter, a greater proportion of the total air must be supplied under the grate, and more draught is therefore required. With finer fuels, i.e. a less porous bed, more draught is also required.

(4) The design of the plant, particularly the cleanness of the flues and their resistance to the flow of waste gases.

### Measurement of Draught.

The simplest form of pressure gauge for the measurement of draught consists of a glass tube, usually about $\frac{5}{8}$ in. in diameter, bent to form a U, fig. 12. This is filled with water to zero on the scale in both limbs, one of which is put into communication with the pressure to be measured, and the other is open to the atmosphere. To prevent excessive evaporation of the

water, it is customary to close the air limb with a brass cap with a pinhole through it, to allow air to enter or leave the limb, and so maintain atmospheric pressure within it.

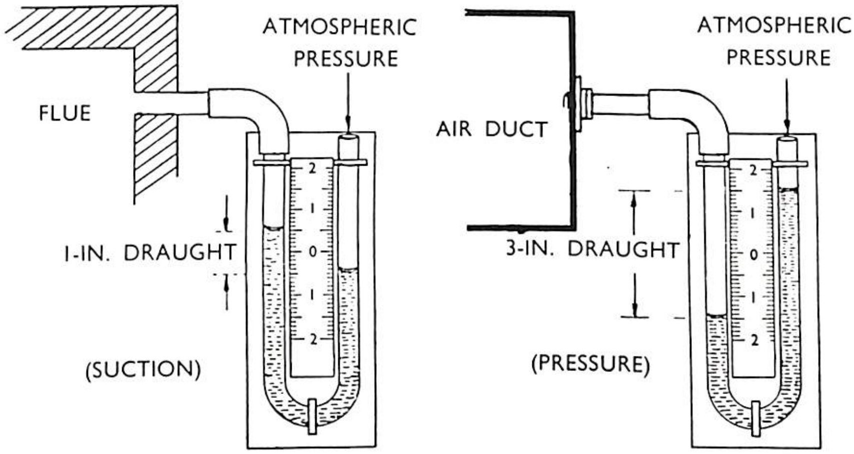



Fig. 12. U-tube draught gauges indicating natural or induced draught and forced draught.

The surface of the water in each leg takes the shape shown and is called the "meniscus." The centres of the lower curves are used when readings are taken.

Draught is thus measured by the difference in the water levels in the two limbs of a U-gauge, one of which is connected to a pipe inserted into the flue, in which it is desired to make a test, and the other is open to the atmosphere. The difference is measured in inches and tenths of an inch of water. In making a test the connection pipe should project into the flue at right angles to the flow of gases, or a correct reading will not be obtained. If the open end of the tube faces the flow, the reading will be too small, and if it faces in the direction of flow it will be too high.

Every Lancashire boiler working under induced draught should be fitted with gauges to indicate the pressure in each side flue. The pipes into these flues should be not less than $\frac{5}{8}$ in. diameter, and the connection should be made with a tee piece to facilitate the cleaning out of soot.

## NATURAL DRAUGHT

The draught or flow of air produced by a chimney is due to the difference between the weight of the column of hot gases within the chimney and the weight of an equal column of atmospheric air outside it. When the gases are heated they expand. The weight of the waste products and air in a chimney thus falls with increase in temperature, so that the rate at which they are thrust up the chimney into the atmosphere by the heavier cooler air, by which the chimney is surrounded, depends upon the difference in temperature between the hot gases at its base and that of the atmosphere. It also depends upon the height of the chimney, as the greater the height the greater the difference in weight between the two columns measured from grate level.

Table IX gives the approximate draught in inches water gauge produced by chimneys of different heights:—

TABLE IX

DRAUGHT PRODUCED BY CHIMNEYS OF DIFFERENT HEIGHTS

(inches water gauge at chimney base)

| Height of stack above grate (ft.) | Temperature at base ° F. | | |
|---|---|---|---|
| | 400 | 500 | 600 |
| 50 | 0.26 | 0.31 | 0.35 |
| 75 | 0.38 | 0.46 | 0.52 |
| 100 | 0.50 | 0.61 | 0.69 |
| 125 | 0.61 | 0.75 | 0.85 |
| 150 | 0.73 | 0.89 | 1.02 |
| 175 | 0.83 | 1.03 | 1.18 |
| 200 | 0.93 | 1.15 | 1.33 |
| 225 | 1.03 | 1.28 | 1.48 |
| 250 | 1.11 | 1.40 | 1.63 |

*The draught in the side flues of a Lancashire boiler without an economiser is usually about half that at the base of the chimney.*

**The Volume of Chimney Gases.**

The volume of carbon dioxide produced in the burning of a carbon fuel is equal to the volume of oxygen used up in its formation. The carbon dioxide formed thus displaces oxygen, and *the volume of chimney gases, measured at the same temperature, is for all practical purposes equal to the volume of air supplied, including excess air.*

The weight of gases discharged does not, however, increase indefinitely with rise in temperature, as other factors enter. *And there is, with any fuel, a definite range of waste gas temperatures for most favourable draught conditions.* This is indicated in fig. 13. This becomes more favourable to fuel economy the greater the weight of the chimney gases. Carbon dioxide is the heaviest gas known so that the higher the $CO_2$ content the greater the weight and the more effective the draught.

**Natural Draught and the Weather.**

The draught needed depends upon the size of the coal, its caking properties and the thickness of the fuel bed, and the demand is not steady except with self-cleaning grates, as ash accumulates on stationary grates between cleaning periods. Typical figures with hand-firing follow those for mechanical-firing when the depth of fuel is the same.

As the weight of air (the actuating force outside the chimney) changes with climatic conditions, natural draught may be seriously affected by changes in the weather. It is also affected by the aspirating action of wind. A moving body of air causes a partial vacuum around its own path towards which air in the vicinity flows at angles more or less approaching right angles, hence a wind blowing across the top of a chimney causes a current at right

angles to itself up the chimney. Natural draught fluctuates also with changes in wind velocity. Apart from the weather, it is the temperature of the gases entering a given chimney which determines the amount of natural draught available at its base.

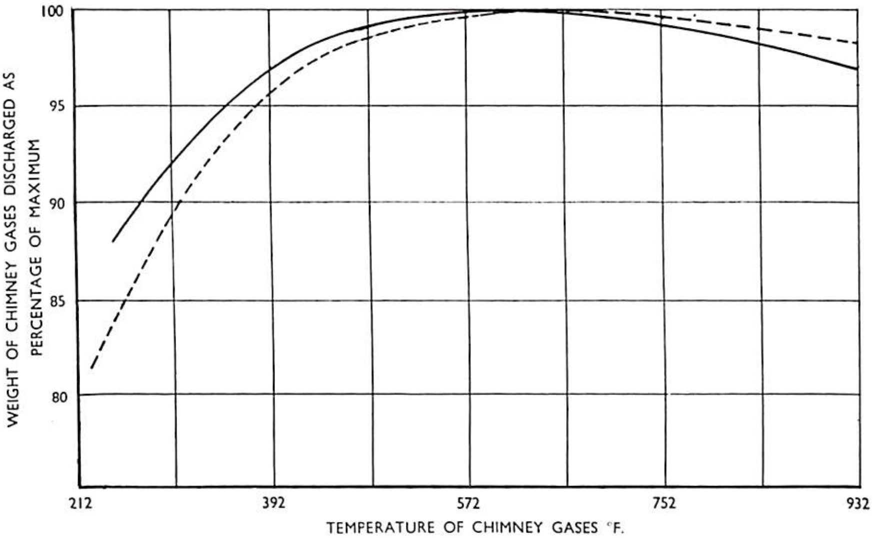



Fig. 13. The temperatures of the gases required at the base of a chimney for most effective draught.

These are calculated for 12 lb. of air used per pound of coal (shown dotted) and 24 lb. of air per pound of coal (shown in full line).

**The Effect of Air Leakage into Boiler Flues.**

Air infiltration, or inleakage into flues, due to faulty furnace fittings, especially loosely fitting dampers, and cracks in brickwork, are frequently responsible for unsatisfactory natural draught.

When checking a plant for air inleakage, the following points should be observed:—

(1) Firedoors should fit tightly.
(2) The ash-pit wall should be sound.
(3) The downtake and side flue covers should be tight.
(4) The joint between the boiler shell and the front-cross wall should be sound.
(5) Dampers should close as tightly as possible.
(6) There should be no inleakage around access doors and damper spindles of an economiser.
(7) Brickwork around the blow-down recess should be sound.
(8) Air should not infiltrate through faulty glazed bricks.
(9) Brickwork should be free from open cracks.

Air infiltration can readily be detected with the aid of a lighted candle or duck lamp, the flame of which is diverted into any cracks or holes through

which air is being drawn. These should be pointed with fireclay or other suitable material until a permanent repair can be made.

**The prevention of air leaks is not so important as the admission of air through open firedoors, as about 85 per cent of the heat transferred to the water in the boiler occurs before the gases reach the side flues. The effect is thus principally to reduce the available draught and by lowering the temperature of the waste gases to reduce also the efficiency of the economiser.**

**The Effect of Open Firedoors.**

Figure 14 shows the percentage of $CO_2$ in the flue gases immediately before, during, and immediately after cleaning the fires of a Lancashire boiler fitted with a stationary grate, with hand-firing using Northumberland singles. No difficulty was experienced in this test (Fuel Research Station) in maintaining a high $CO_2$ content in the waste gases (14 to 15 per cent) while the fires were being prepared for cleaning or when building them up afterwards, but when cleaning was in progress the proportion of $CO_2$ fell for a time to about 7 per cent. The average over the cleaning period was 8.75 per cent. Taken by itself, this implies an appreciable loss of heat during cleaning.

The temperatures recorded during the same cleaning period are shown in fig. 15.

The effect of admitting additional air through open firedoors is further illustrated in the following test record:—

| Period | Carbon dioxide per cent | Carbon monoxide per cent | Oxygen per cent | Nitrogen per cent |
|---|---|---|---|---|
| 70 minutes continuous running .. | 12.82 | 0.07 | 6.26 | 80.83 |
| 1 hour, including cleaning .. .. | 11.58 | 0.30 | 7.27 | 80.49 |
| 3 hours continuous running .. .. | 14.43 | 0.17 | 4.35 | 80.93 |
| 1 hour, including cleaning .. .. | 12.11 | 0.20 | 6.99 | 80.59 |
| 110 minutes continuous running .. | 14.15 | 0.06 | 4.79 | 80.93 |
| Average .. .. .. | 13.48 | 0.15 | 5.42 | 80.93 |

This gives the mean analysis of continuous samples of flue gases collected from the two side flues over two periods of one hour, including the cleaning period; and over three periods of steady running before, between, and after the cleaning periods referred to in figs. 14 and 15.

The average percentage of $CO_2$ in the flue gases for the two periods during which the fires were cleaned was 11.84 compared with an average of 14.03 per cent during the periods of steady running, and 13.48 per cent over the whole trial.

**The Effect on Excess Air of Varying the Load with a Fixed Firedoor Opening.**

It has been found that with a given opening in the firedoor for a secondary supply of air, the percentage excess air remains the same at all loads; that is, with increase in draught the secondary supply of air remains proportional to the load.*

* The square root of draught over a fire is directly proportional to the boiler load, and the amount of air passing through the openings in a firedoor is proportional to the square root of the pressure drop.

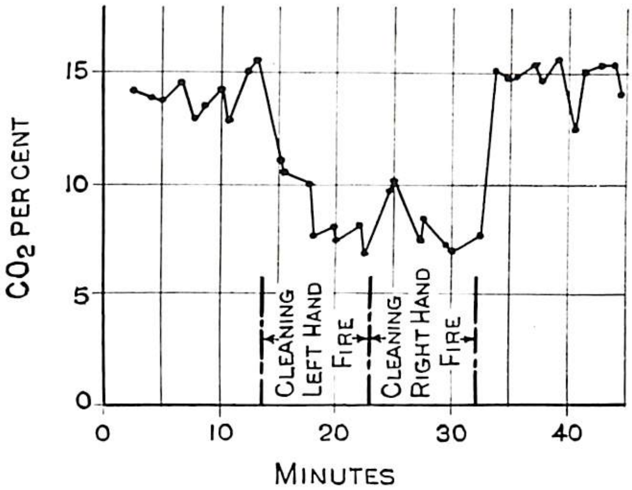



Fig. 14. The percentage of carbon dioxide in flue gases immediately before, during, and immediately after cleaning fires with a hand-fired stationary grate. The average for carbon dioxide over the whole cleaning period was 8.75 per cent.

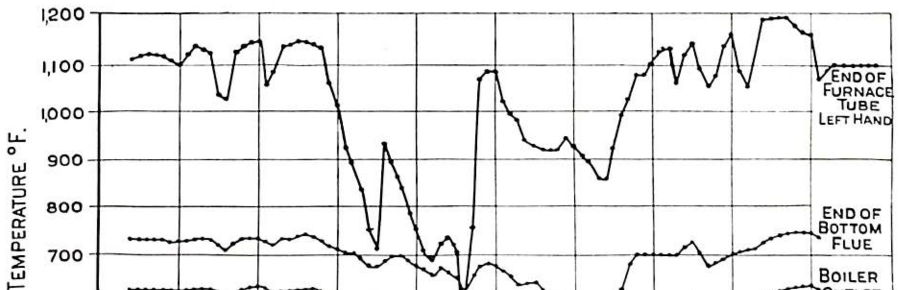



Fig. 15. The temperatures during the cleaning period covered by fig. 14. The temperature drop at the end of the furnace tube being cleaned was 500° F. during this period, and 300° F. at the end of the other furnace tube.

### The Control of Natural Draught.

Given adequate natural draught, and an air-tight setting, the first step towards effective control of the supply of air is the correct spacing of the firebars. This is determined largely by the size of coal to be used. When the spaces are too large, small pieces of coal and coke fall into the ash-pit and are lost if they are not recovered by riddling the ashes.

A draught gauge should be connected to each side flue in front of each damper by which to check adjustments, such as those made to prevent the inrush of cold air when firedoors are opened, and provision made for the adjustment of side dampers from the front of the boiler. This is made easier if the dampers are counterbalanced by weights as shown in fig. 16.

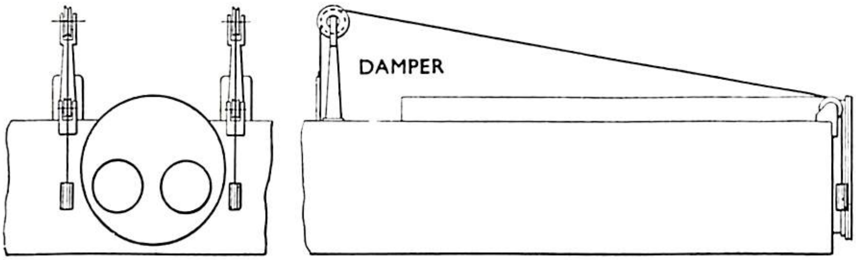



Fig. 16. Side dampers fitted with counterbalance weights at the front of the boiler to facilitate adjustments.

A more satisfactory and much neater arrangement is shown in fig. 17. The damper pulley shaft is extended and a small drum is fitted to it. This is coupled to a winch mounted on the boiler front by a steel wire rope, the counterbalance weight being adjusted so that when the rope is slack the damper is in the closed position. The load carried by the rope is the difference between the weights of the damper and the counterbalance.

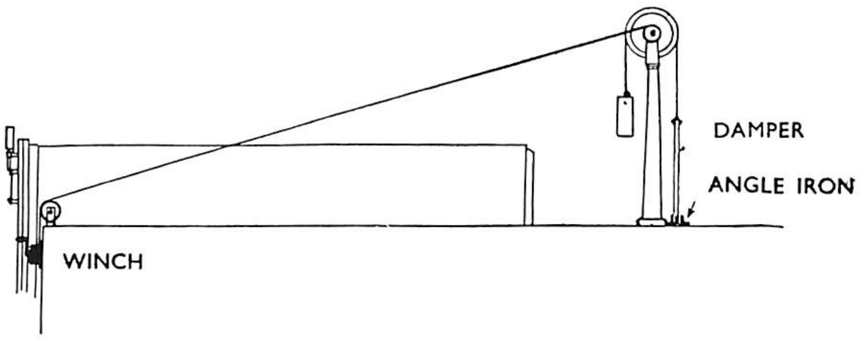
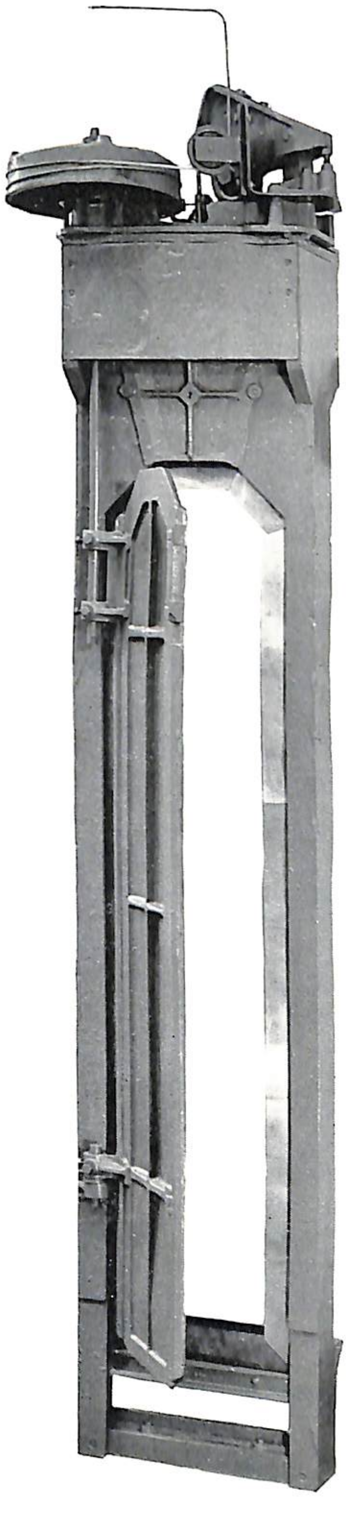



Fig. 17. Side dampers counterbalanced and operated by a winch at the front of the boiler.

This diagram also shows a method of sealing a damper opening with a sliding clamp. The clamp is made up of two lengths of 2 in. by 2 in. angle iron which fit loosely, one on each side of the damper, with square distance pieces and a bolt at each end. These close the opening between the damper and the slot in which it works. The angles are not fixed but are free to rise and fall with the damper should it become buckled.

A more satisfactory way of achieving this sealing is by fitting a deep hood over the top of the damper frame through which only the wire rope

Fig. 18. The Metro-Flex side-flue damper.



supporting the damper can pass, as in the Haywood damper. This reduces the air gap to a minimum.

*A side damper of the gate type* is shown in fig. 18. This is not affected by warping, jamming or flue dust, and ensures an even distribution of gas flow over the whole height of the flue, thus giving rise to improved heat transfer. It is opened and closed manually, and when closed a gas-tight joint is made. As it closes, it presses against heat-resisting flexible strips and the difference in pressure on opposite sides of the damper, due to the draught, perfects the seal. The damper is closed by the action of a counterweight in the head gear. The mechanism for opening the damper, against the force of the counterweight, is shown in fig. 18, and the position of the damper is indicated by a simple pointer and scale. Air infiltration through the top is prevented by an expansion seal. This is accessible and may be packed while the boiler is in operation.

The possibility of the gate jamming, due to an accumulation of flue dust

at the bottom of the opening, is overcome by an automatic flue-dust ejector which is operated by the first part of the action of opening the damper. The gate is suspended on, and pivoted by, a vertical shaft which is carried on a self-lubricating bearing fitted to the top of the damper frame. It is not, therefore, in the gas stream, and is accessible from outside the flue.

*Swivel-type dampers* are used with economisers. With these the lever should be attached to the swivel or other regulating gear and work in a quadrant, with two holes in it so that the damper may be held firmly in position by a steel pin. This is necessary also with main dampers to prevent them being closed accidentally with possible "blow back" and danger of injury to the boiler operator.

*Draught distribution from a main flue.* When the flues from a number of boilers discharge into a main flue, the side dampers of the boiler nearest to the chimney are opened least, and those of the boiler farthest away the most, in order to affect a uniform distribution of the draught. This observation also often applies to the two side flue dampers of a single boiler.

**The Regulation of the Supply of Air over the Grate.**

*The bad effect upon the performance of a boiler of admitting insufficient air over a fire* is most clearly seen in the emission of "distillation" brown smoke, or "sooty" black smoke from the chimney.

Tests on the emission of black smoke by vessels at sea have led to the discovery that the standard firedoors of Lancashire boilers with natural draught, in which air is supplied through a series of vertical slots of a total area of 40 sq. in., do not supply sufficient air to burn the volatile matter distilled from bituminous coals. In tests with alternate side-firing at 10-minute intervals with Northumberland singles with a total air supply 120 per cent of that theoretically required, heavy smoke was emitted from the chimney. It was observed that this emission of smoke occurred for only a limited period after firing (see fig. 6). A firedoor was therefore designed with an opening for the secondary supply of air, of 32 sq. in. for continuous air, and 29 sq. in. for supplementary air, making 61 sq. in. in all. This enabled the emission of smoke to be eliminated.

The percentage of $CO_2$ in the flue gases in these tests was almost constant from 13 to 14 per cent whatever the intensity of smoke emitted. Boiler efficiency fell steadily from 72 per cent with no smoke to below 60 per cent with black smoke, and excess air varied from 33 per cent with no smoke to about 20 per cent with black smoke. The exit temperature of the waste gases being almost constant.

It was thus established that a consistently high percentage of $CO_2$ in the waste gases is not by itself an indication of good combustion. Maximum efficiency requires also no emission of smoke; i.e. a slight haze at the top of the chimney. The reduction in efficiency with heavy smoke owing to unburned combustible gases may be over 10 per cent.

**The practical test of combustion efficiency is therefore a high $CO_2$ content in flue gases, accompanied by an almost complete absence of smoke at the chimney top.**

**Smoke Eliminator Doors.**

The main features of the smoke eliminator door designed for hand-firing are:—

(i) Larger openings than those in the standard door to admit more air over the fire.

(ii) This air is so admitted that more intimate mixing with the combustible gases occurs.

(iii) The quantity of air admitted can be varied to allow for the fact that the bulk of the volatile matter is evolved shortly after firing (see fig. 6).

The construction of the door is shown in fig. 19. It will be seen that a continuous supply of air passes through two large streamlined nozzles, each $4\frac{1}{4}$ in. in diameter. This relatively thick jet of air penetrates much farther into the furnace and gives greater turbulence than the same area of small jets.

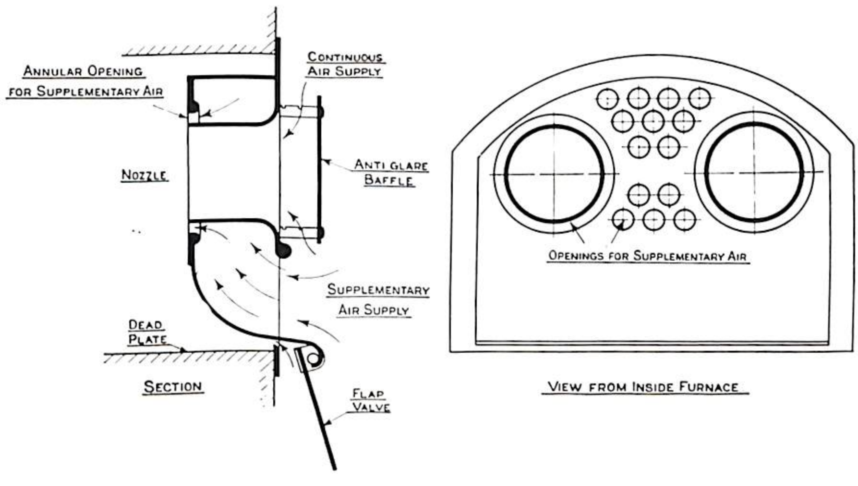



Fig. 19. F.R.S. smoke eliminator door for natural draught hand-fired Lancashire boilers.

The maximum secondary air supply openings are: continuous air, 32 sq. in.; supplementary air, 29 sq. in.; and total air, 61 sq. in.; compared with 40 sq. in. for continuous air only with the standard door.

The nozzles project through a box formed on the inside of the firing door, and the supplementary air enters the box through a large rectangular opening near the base. It then passes through annular spaces round the nozzles and, to a much smaller extent through a number of holes in the face of the box, into the furnace. The supplementary air is controlled by a side flap valve which opens automatically under the action of gravity whenever the firedoor is opened. This is closed by hand when the evolution of volatile matter has abated. The time to close it is determined by trial and error whenever the coal is changed, *and is not affected by variations in boiler load.*

A baffle plate is provided in front of the air nozzles, partly to shield the eyes of the fireman from glare, and partly to enable the continuous secondary air supply to be restricted or cut off when necessary The position of the baffle plate may be varied by moving it from one to another of three sets of notches cut in the four pins which support it. All the openings through which air has to pass are streamlined, and fine adjustments are not necessary. The doors are made of mild steel or of cast iron, or partly of cast iron and partly of mild steel.

Another method of increasing the secondary supply of air is to increase the "pull" over the fire by increasing the resistance of the fuel bed, and thus cause more air to be drawn through the firedoors. This occurs automatically when smaller fuel is fired. For example, during tests with Northumberland singles and smalls and the same boiler load, the pull over a fire rose from 0.12-in. w.g. with singles to 0.19-in. w.g. with smalls, the amount of excess air being increased by this from 20 to about 33 per cent. Smoke emission was reduced to one-quarter, the percentage heat lost due to incomplete combustion was reduced to one-third, and the thermal efficiency of the boiler rose by 4 per cent.

*There is no substitute for the control of combustion air based upon the $CO_2$ content of the waste gases, and the absence of smoke at the chimney stack.*

**Disadvantages of Natural Draught.**

The use of natural draught suffers from the following disadvantages:—

(1) Comparatively high and costly chimneys are required.

(2) The exit temperature of the waste gases must be higher than it need be with consequential greater heat loss and lower efficiency.

(3) The intensity of draught is affected by the weather.

## PRODUCTION OF DRAUGHT BY STEAM JETS

A jet of steam at high velocity is discharged centrally into a tube (see fig. 40). This induces a flow of air towards it with which it mixes and shares its momentum. The method, however, is not one which is readily controllable when differing thicknesses of firebed have to be used, as indicated by Table X.

TABLE X

WEIGHTS OF AIR INDUCED BY STEAM JET* WITH VARIOUS THICKNESSES OF FUEL BED

| Pressure lb./sq. in. gauge | Thickness of fuel bed (in.) | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 4 | 6 | 8 |
| | lb. | lb. | lb. | lb. | lb. |
| 50 | 8 | 5.5 | 4.5 | 4 | 4 |
| 100 | 13 | 9 | 8 | 7 | 7 |
| 150 | 17 | 13 | 12 | 8 | 8 |

* In round figures.

The production of draught by steam jets is widely used because of its simplicity, reliability, low initial cost, and the secondary advantage of reducing clinker and cooling grate bars.

**The Most Advantageous Size of Orifice and Range of Steam Pressures for Jets**

The most effective size of orifice for steam jet air injectors is $\frac{1}{16}$ in.; and from Table XI it will be observed that the most economical pressure is from 25 to 50 lb. per sq. in. gauge.

TABLE XI

WEIGHTS OF AIR INDUCED BY STEAM JET INTO A 4-IN. DIAMETER COMBINING TUBE WITH DIFFERING FUEL BEDS (nozzle diameter $\frac{1}{16}$ in.)

| Steam pressure lb. per sq. in. gauge | Fuel beds | | |
|---|---|---|---|
| | Coke | 1-in. singles | 1-in. slack |
| 25 | 41.8 | 31.6 | — |
| 50 | 45.4 | 34.6 | 26.0 |
| 75 | 40.8 | 32.6 | 25.3 |
| 100 | 36.8 | 29.8 | 23.2 |
| 125 | — | — | 22.4 |

**The Amount of Steam Required to Produce a Given Draught.**

The proportion of the steam output required for forced draught by a boiler fitted with a 4-in. diameter combining tube, well-designed bars, and $\frac{1}{16}$-in. diameter nozzles can be shown to be approximately 2.7 per cent.

**Comparison of Steam-Jet and Fan-Forced Draught.**

Considering the quantity of steam required by a steam jet under the most favourable conditions with a well-designed combining tube and a $\frac{1}{16}$-in. diameter orifice, the percentage of the total output required is 2.7 per cent. Results are very poor with $\frac{1}{8}$-in. diameter orifices, and wastage becomes progressively more serious as the inevitable erosion of the nozzle proceeds. Experience indicates that a more usual figure is not less than 5 per cent.

Assuming this is a reasonable figure to take and the rate of evaporation is 8.5 pounds of steam per pound of coal, the equivalent power consumption of steam jets is shown in Table XII.

TABLE XII

EQUIVALENT POWER CONSUMPTION OF STEAM-JET FORCED DRAUGHT

| Boiler evaporation lb. per hour .. .. .. | 6,000 | 7,000 | 8,000 | 9,000 | 10,000 |
|---|---|---|---|---|---|
| 5 per cent of this .. .. | 300 | 350 | 400 | 450 | 500 |
| Pounds of coal required for forced draught .. .. | 35.2 | 41.2 | 47.0 | 53.0 | 58.8 |
| Equivalent electrical horse-power at 1 kilowatt-hour per 1.5 lb. .. .. | 23.4 | 27.4 | 31.2 | 35.2 | 39.2 |

The horse power required to produce an equivalent fan-forced draught is 4 to 7.5 h.p. (2 to 3.75 h.p. per furnace) for this range of evaporations.

It is clearly impossible in these days to justify the use of upwards of 3 per cent of the coal used to produce the steam needed by steam-jet injectors to produce forced draught. Not only is there a waste of coal, but there is a loss of upwards of 3 per cent of the steaming capacity of the boiler for power and process work.

## FAN DRAUGHT

The performance of an existing natural draught installation can usually be improved by installing auxiliary fan equipment. This ensures adequate supplies of air irrespective of the weather, and enables thicker fires and therefore lower grade coals to be used.

**Fans.**

The essential components of a fan are the impeller, the casing, and an inlet cone, fig. 20. The impeller consists of fan wheel and hub, keyed to a shaft, which is supported by sleeve, ball or roller bearings. Sleeve bearings

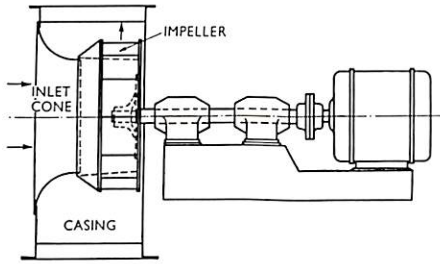



Fig. 20. The elements of a fan.

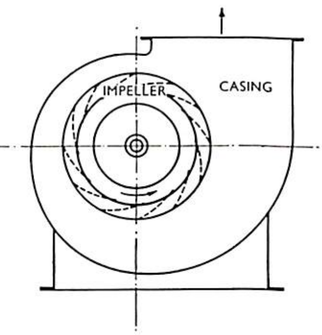



Fig. 21. A centrifugal fan.

on each side of the fan wheel are to be preferred, but where cost is of first importance it may be necessary to keep both bearings on the motor side of the impeller, with the fan wheel overhung, or even, in the case of small fans, to overhang the wheel directly on an extension of the motor shaft. The fan wheel runs free in the casing without contact, and no internal lubrication is required. Air or flue gas is directed towards the centre of the fan wheel by the inlet cone, and is accelerated outwards by the rotating fan blades and discharged at an increased pressure from the fan outlet. The fan impeller is balanced to give vibrationless operation throughout its range of working speeds. Mechanical breakdown is rare and efficiency of operation is not affected by length of service.

**Application of Fan Draught.**

There are two ways of applying fan draught. Air may be caused to pass through the fan before entering the furnace; this is known as forced draught. Alternatively, the fan may be placed near the base of the chimney to draw air through the furnace; this is induced draught. Forced draught is designed

to overcome the resistance of the grate and the bed of fire upon it. Induced draught takes the place of the natural draught of a chimney, chimney height then being determined principally by the need to discharge the products at the height fixed by local by-laws. With induced draught, all the hot products pass through the fan. About one and a half times the volume of gases has therefore to be handled as with an equivalent forced draught. Hence, for the same intensity of draught and the same weight of air or gases per minute, an induced draught fan needs to be larger, and because of its size requires more power. Induced draught fans also have to withstand the comparatively high temperature of waste gases, some of which are corrosive, and these fans are therefore made more robust.

When fan forced draught is used with Lancashire or vertical boilers the front of the ash pit is closed. Air from the fan is then delivered through ducts to below, and often above and below, the grate (see fig. 56).

**Air Inleakage and Fan Draught.**

With forced draught, the pressure of the gases at the firedoor is close to or slightly greater than that of the atmosphere, the "negative pressure" or "suction" at all points in the flues is therefore less than with induced draught, and there is less inleakage of air through brickwork. Forced draught must therefore be cut off when ash-pit or furnace doors are opened, to avoid the risk of injury to the fireman. This is effected automatically in the design shown in fig. 56.

**Types of Fans.**

Fans may be divided into two classes—centrifugal and axial flow—depending upon the direction of air flow through the impeller. In centrifugal (or radial flow) fans the air flows into the eye of the fan, and is discharged

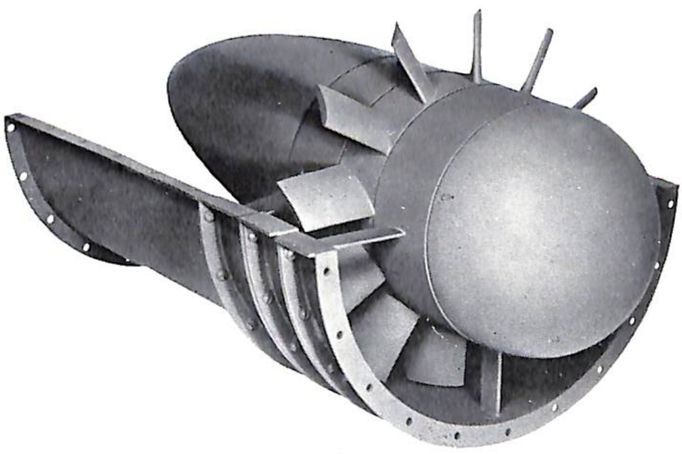


Fig. 22. An axial flow fan.

from the periphery at right angles to the direction of entry (fig. 21). In axial flow fans the direction of flow from inlet to outlet remains unchanged (fig. 22).

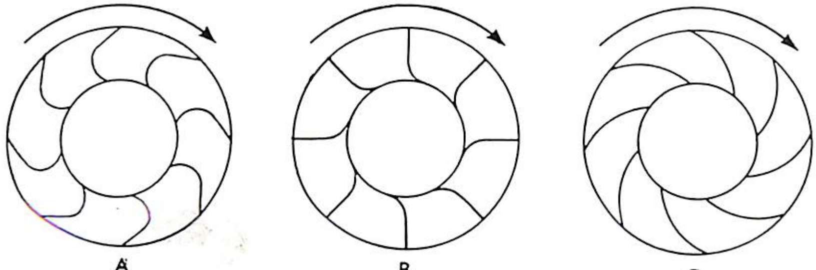



Fig. 23. Three types of impellers for centrifugal fans:
(*a*) With forward blades or vanes; the outer ends are inclined in the direction of rotation.
(*b*) With radial blades or vanes; the outer ends are radial.
(*c*) With backward blades or vanes; the outer ends are inclined back from the direction of rotation.

Fig. 24. A radial bladed impeller for an induced draught fan.

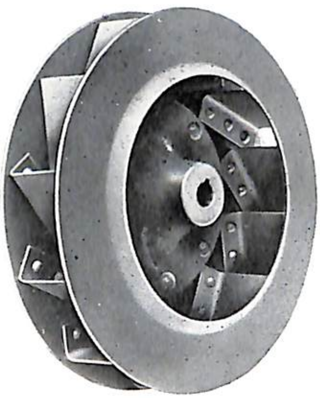


Fig. 25. A backward bladed impeller for a forced draught fan.

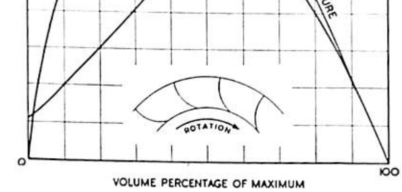



Fig. 26. Characteristic curves for a radial bladed induced draught fan.

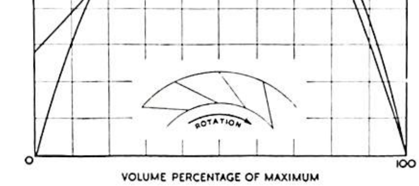



Fig. 27. Characteristic curves for a backward bladed forced draught fan.

**Fan Blades.**

The rise in pressure which can be obtained by the use of a centrifugal fan depends upon the design of the impeller, the most important factor being the shape of the vanes or blades. The three most important shapes are shown in fig. 23, and typical fan wheels in figs. 24 and 25. The performance curves for a radial bladed induced draught fan are shown in fig. 26; and for a backward bladed forced draught fan in fig. 27.

The forward curved blade has its point of maximum efficiency at the design load, and has no reserve of pressure with which to overcome dirty boiler conditions. The range of duties which a fan performs at its maximum efficiency, and the reserve of pressure available to overcome additions to them, increases progressively as the shape of the blade is changed from forward curved through radial to the backward curved form.

For forced draught work it is usual to select either the backward curved blade (for high efficiency and hence reduced running costs) or the forward curved blade which has a low initial cost but slightly higher running costs.

The radial tipped blade is usually preferred for induced draught fans because of its greater resistance to erosion and the lower tendency for grit in the gas stream to build up on the back of the impeller blades, as is the case with backward bladed impellers.

**Forced Draught Fans.**

Backward blades are also to be preferred with centrifugal fans for forced draught with stoker-fired shell boilers as they allow the maximum variation in delivery pressure with a given quantity of air, and can therefore be adjusted to deliver, within limits, the same quantity of air, against a varying fuel bed resistance. The power used, like the pressure, rises to a maximum which cannot be exceeded, so that a margin for possible overload is not necessary in the driving unit, nor can the driving motor sustain damage if the resistance of the system should prove to be lower than is allowed for in the design. Axial fans also have this characteristic but tend to be noisier than centrifugal fans, and are not much used with shell boilers.

**Forced Draught for Stoker Firing.**

Caking coals offer a greater resistance to air flow than non-caking coals. Small coals pack more tightly on a grate than large coals, and air spaces in the grates designed to burn them are made proportionately smaller. This means a greater resistance to air flow both by the grate and the fuel. Low volatile coals burn best with a somewhat higher air pressure than is used with bituminous coals, as they have a higher ignition temperature.

Forced draught fan equipment must be able to deliver the maximum quantity of air required for the complete combustion of the range of coals which a grate is designed to burn at the maximum continuous rating of the boiler. A reduction in fan output is therefore necessary at normal load and means must be provided to achieve this economically.

It is considered the better practice in the application of forced draught to shell boilers to use one fan for each boiler, or one fan for each furnace.

This gives the greatest flexibility to meet varying loads, either with a single boiler or with a group of boilers, and also reduces difficulties which can arise, owing to breakdown, to a minimum. Control may be also more effective, as the resistance of no two furnaces is necessarily the same. When a single large fan is installed to serve a group of boilers a damper control should be arranged for the supply to each furnace.

**Draught Required.**

Although mechanical stokers have not yet been considered, it is helpful to know that the natural or induced draught normally required over the fire with sprinkler and coking stokers is as follows:—

TABLE XIII

NATURAL DRAUGHT TO BE PROVIDED OVER THE FIRE WITH SPRINKLER AND COKING STOKERS AND DIFFERENT COALS

| | Shovel sprinklers, in. w.g. | Rotary, in. w.g. | Coking stokers, in. w.g. |
|---|---|---|---|
| Free-burning coals . . .. .. | 0.2–0.3 | 0.25 | — |
| Slightly caking coals .. .. | 0.2–0.3 | 0.25 | 0.4–0.6 |
| Medium caking coals .. .. | 0.25–0.35 | 0.4 | 0.6–0.7 |
| Strongly caking coals .. .. | 0.35–0.5 | 0.5 | — |

The pressure at which forced draught fans must deliver air depends upon the resistance of the plant, the resistance of the grate and the size and depth of the fuel. The depth of fuel is least with sprinkler stokers. Average values required over the fire for plant newly cleaned are from 0.1 to 0.2-in. w.g., depending upon the grade of coal to be burned.

**Induced Draught Fans.**

A fan with different characteristics is required to induce draught, as the pressure required at the outlet is uniform within narrow limits. Radial blades are preferred. They are self-cleaning except for sticky dust, are less liable to distortion by centrifugal force and therefore more suitable for high temperature conditions. The power required is not, however, self-limiting, so that a margin has to be allowed in the h.p. of the motor to meet a possible overload, or a safety device must be fitted.

**Typical Induced Draught Pressures for Lancashire Boilers.**

Typical figures for induced draught with a Lancashire boiler (natural draught or fan draught) are $\frac{5}{8}$ in. in side flues, $\frac{7}{8}$ in. at economiser inlet, and $1\frac{1}{4}$ in. at the fan. These figures may, however, be considerably increased under dirty boiler conditions to as much as 1 in., $1\frac{1}{4}$ in. and 2 in., respectively. When dust collectors are fitted provision must be made for an additional 1 in. to $1\frac{1}{4}$ in. of draught to overcome the pressure drop due to the collectors.

**The Application of Induced Draught.**

The layout of two Lancashire boilers with economisers, chimney and induced draught fan is shown in fig. 28. Swivel dampers are arranged to allow the plant to be operated under natural draught, with the economisers

and induced draught fan by-passed. The induced draught fan is usually run at a constant speed with the main damper control at the inlet, the side flue dampers being used to make fine adjustments.

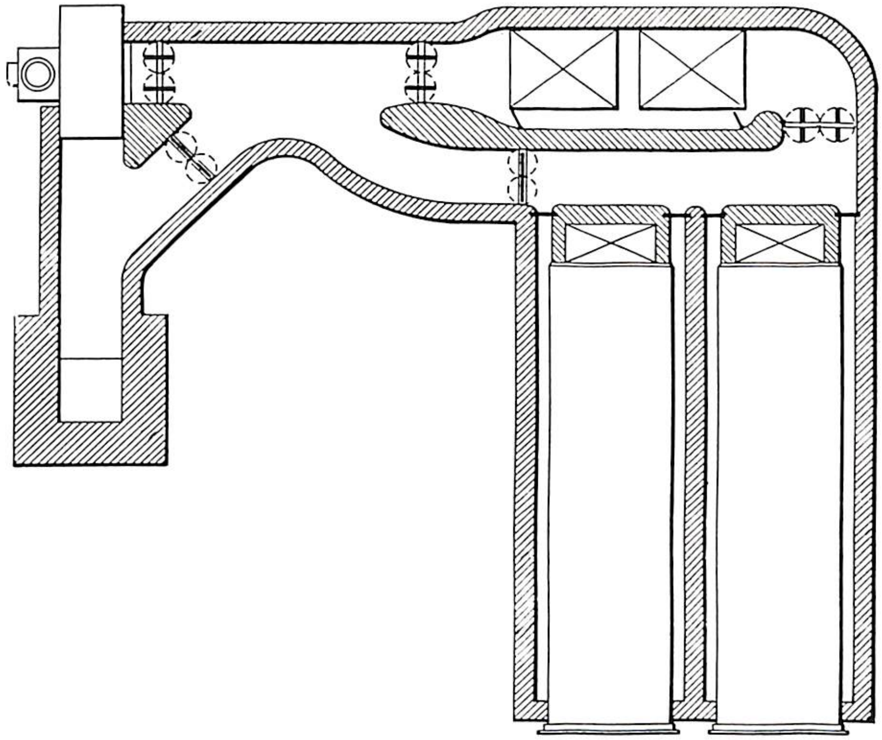


Fig. 28. A plan in section of an installation of two Lancashire boilers, with economisers and an induced draught fan. Note the swivel dampers and that by their use the boilers may operate on natural or induced draught, with or without economiser.

The application of an induced draught fan depends for its maximum effect, as does a chimney, upon the resistance of the system being kept as low as possible. The design features which make for high resistance and which should therefore be avoided, are:—

(1) Unnecessarily long flues and passages. Gas flow should be as direct as possible.

(2) Abrupt changes in cross-sectional area. Changes in the cross-sectional area of flues and passages should be effected gradually.

(3) Sudden changes in direction of gas flow. These absorb pressure and reduce the effective cross-sectional area. Easy curves of large radius should be arranged.

Points in operation and maintenance which also make for high resistance are:—

(1) Deposits of dust. It is important to fuel economy to keep flues and ducts clean.

(2) Leakage of cold air into the boiler system either by infiltration through the brickwork or damper settings, or as excess air through the furnace.

(3) The formation of scale on the impeller. This alters the shape of the blades and unless uniformly distributed causes out of balance running.

**The Temperature of Waste Gases when I.D. Fans are Used.**

The maximum temperature at which induced draught fans of mild steel normally operate is 750° F., as mild steel loses strength rapidly at temperatures over 500° F. Steels with a high resistance to wear such as high carbon chrome alloys and manganese steels cannot be worked economically into blades, so that the working life and the availability of induced draught fans depend upon their construction. The bearings of induced draught fans handling waste gases above 400° F. should be water cooled.

Induced draught fans allow waste gases to be discharged into the chimney at a lower temperature than with natural draught for the same duty. An economiser may therefore be installed to heat the feed water, and thus help to avoid overheating fan bearings and other parts (see figs. 32 to 37).

An induced draught fan does not remove the need to use a chimney to conduct waste products into the atmosphere at a height satisfactory to local authorities.

**Balanced Draught.**

Grades of coal with a greater percentage of fines and a higher ash content than in pre-war days are now becoming increasingly available for steam raising. These call for higher air pressures under the grate than can be economically achieved by natural draught. The practice is consequently growing of installing forced draught fans to supply air under the grate, with natural or induced draught to exhaust the products of combustion to the base of the chimney. The result is spoken of as a balanced draught.

Balanced draught has the advantages of both forced and induced draught and is now widely used with medium and large boiler plants. The system enables most favourable draught conditions to be used for the burning of the widest possible range of coals with a given plant, and is extremely flexible. When operating on light loads, for example, forced draught fans can frequently be shut down. Pressure conditions over the grate being very nearly neutral, with a pressure slightly less than atmospheric being maintained at the firedoors. This reduces the liability to overheat the baffle plates. More sensitive pressure gauges reading, say, from $-2$ in. to $+2$ in. in hundredths of an inch water gauge, are therefore required.

**Fan Drives: General.**

Fans may be driven by:—

(1) Variable-speed machines.

(2) Multi-speed machines.

(3) Constant-speed machines.

Variable-speed machines enable fans to cover a wide range of duties without sacrificing fan efficiency and without the need for output control devices. They include reciprocating steam engines, steam turbines, D.C.

motors, A.C. slip ring-type motors and A.C. commutator-type motors. A.C. driven variable-speed motors are, however, comparatively expensive, and are not normally used to obtain control of fan output on shell boilers. A constant speed motor is generally used owing to its simplicity, reliability and economy.

**Fan Drives Used with Shell Boilers.**

The steam engine is widely used to drive forced-draught fans which supply batteries of Lancashire boilers. A motor-driven forced-draught fan with ducting for primary or secondary supplies of air to two boilers is shown in fig. 102. The majority of fans used for forced or induced draught with small installations of shell boilers are driven by a direct-coupled electric motor mounted on the same bedplate. Power transmission with small installations may be by a belt, a V-rope or a chain drive, and advantage is sometimes taken of this to effect a change in speed by a change of pulleys.

**Control of Fan Output.**

The output of a motor-driven fan with a constant speed may be controlled by:—

(1) The speed of the impeller or fan.

(2) dampers.

*Regulation by speed* is practical only with relatively large units, apart from the use of stepped pulleys and a belt drive, say, with an induced draught fan.

**Control by Damper.**

Flow may be regulated by a damper, which introduces a variable resistance into the system at the inlet or outlet of the fan or by vanes in the inlet so arranged and controlled as to give a variable amount of pre-swirl to the air or gases before they enter the impeller.

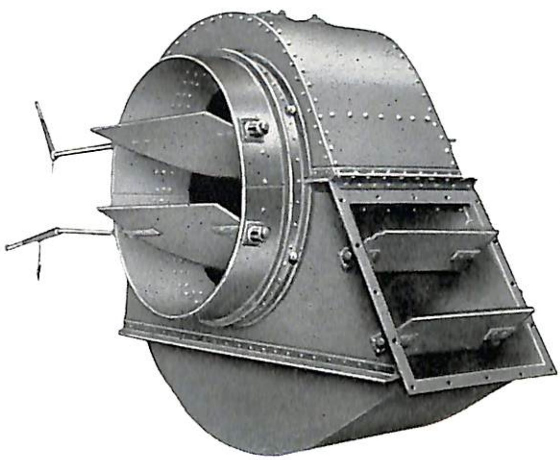


Fig. 29. Twin-swivel type dampers fitted to induced draught fan equipment.

Dampers are usually fitted both on the inlet and discharge sides of induced draught fans. They may be of the sliding type, or of the swivel and twin swivel type, or the hinged type. Twin swivel type dampers are shown in fig. 29. The dampers on the inlet are circular and those on the outlet rectangular in shape. Hinged dampers have the advantage that they offer

no obstruction to the gas stream when full open. A "Sirocco" semicircular damper arrangement is shown in fig. 30. Control of induced draught fans may be effected from the firing floor, by interlinked levers and quadrants. An automatic interlocked control is occasionally used, or the dampers on the fan may be set, and fine adjustments made by the side dampers, or, when an economiser is fitted, by the exit dampers from the economiser.

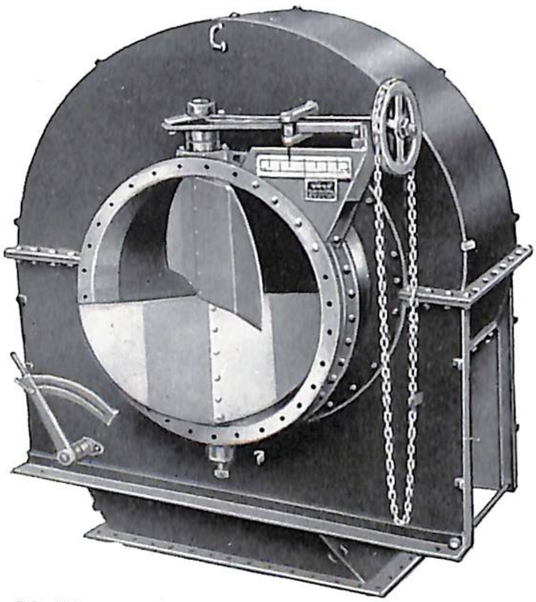


Fig. 30. "Sirocco" semicirc inlet regulator arranged for manual control.

Damper control is simple, reliable, robust and the least costly to install. When the volume has to be halved the damper is closed until more than three-quarters of the pressure developed by the fan is destroyed by it. The power absorbed by the fan, however, is reduced only slightly by this. The running costs are therefore rather higher. This method is therefore restricted to small or medium-sized installations of shell boilers, where the variation in load is not sufficient to cause a serious drop in the efficiency of a fan.

**Inlet Vane Control.**

Inlet vane control can also be used on any installation. It is usually desirable to fit inlet vane control with forced draught fans when the range of pressure required is fairly wide, in order to meet widely differing fuel bed conditions.

*Vane control* is effected by adjustable pivoted vanes which may be placed either axially or radially at the fan inlet. Fig. 31 shows the Howden vane control as applied to forced draught fans for shell boilers. Closing the vanes creates a swirling motion within the air stream, and proportionately

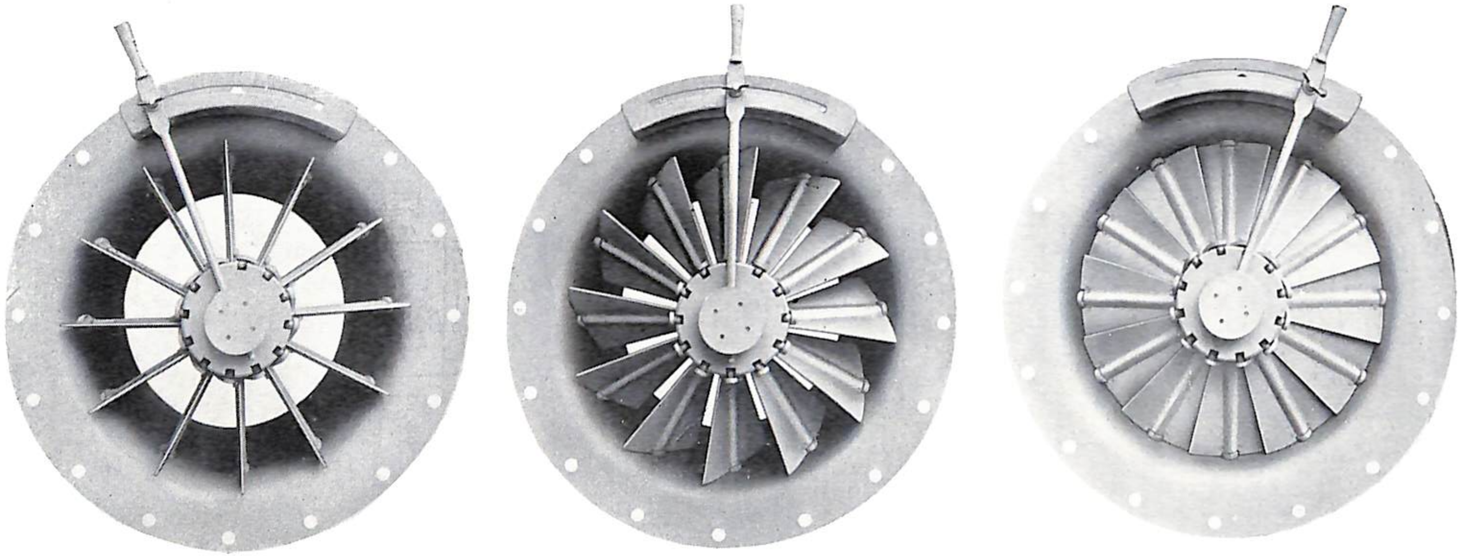


Fig. 31. Vane control for a forced-draught fan for Lancashire boilers, of the type being developed for chain grates, showing full open, half open and closed positions.

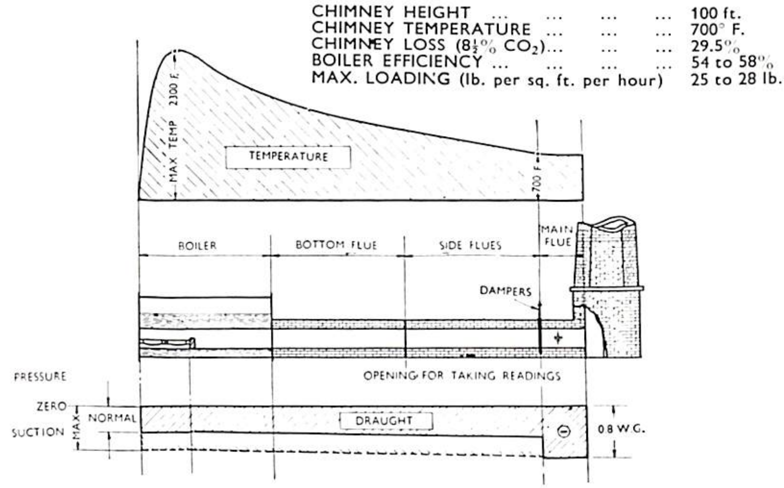



Fig. 32. Temperature and draught characteristics for a natural draught Lancashire boiler.

The approximate fall in temperature through the plant is indicated by the curve above the boiler outline and the draught by the curve below. The heat of the waste gases provides a "suction" at the base of the chimney of 0.8 in. w.g. The chimney loss is 29.5 per cent of the coal burned. Some of this may be recovered by installing an economiser (fig. 33). The burning rate is limited by draught.

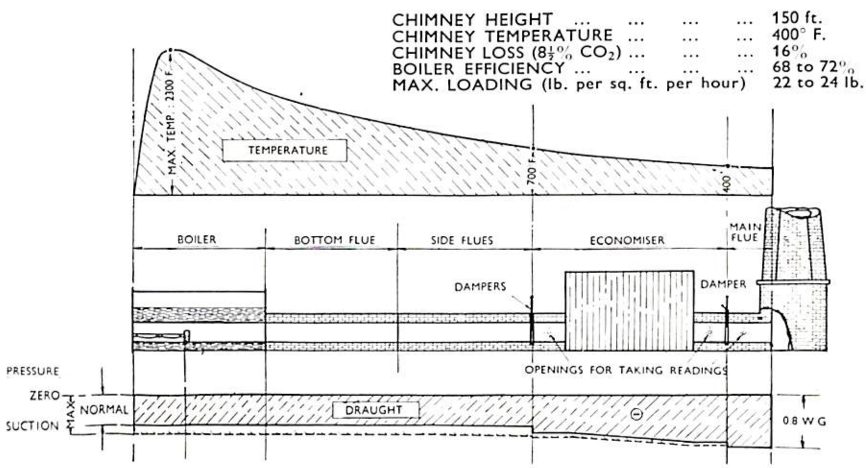



Fig. 33. Temperature and draught characteristics of a natural draught Lancashire boiler with an economiser to recover some of the heat which would otherwise be lost in the chimney gases.

This is based on fig. 32 and the same output of steam. The chimney has been increased in height to give the same draught with waste gases at the lower temperature. The increase in efficiency is reflected in a lower burning rate for the same load.

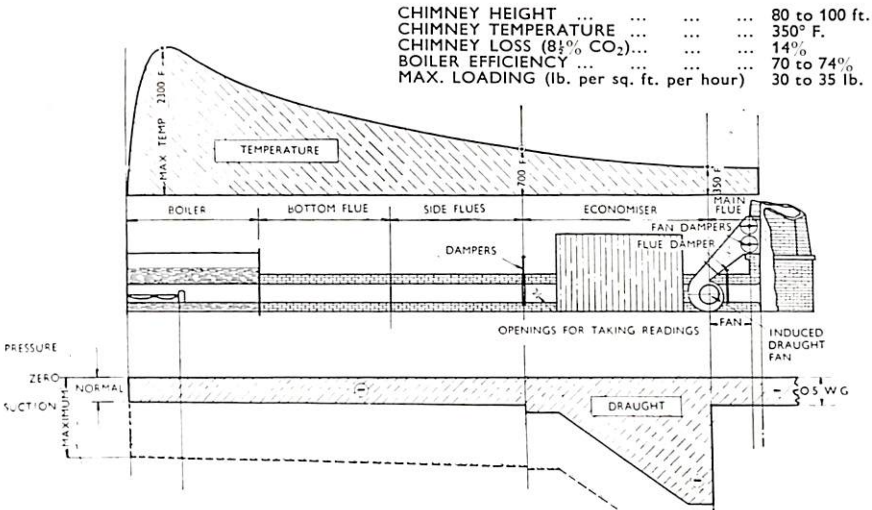



Fig. 34. Temperature and draught characteristics of a Lancashire boiler equipped with an induced draught fan with variable speed drive.

The exit gas temperature has been reduced to 250° F. by the larger economiser, chimney losses are thereby reduced, and the boiler efficiency increased. The chimney is shown 80 to 100 ft. high, the height being determined solely by the need to discharge the products clear of surrounding buildings. Burning rate is limited by the maximum fan draught.

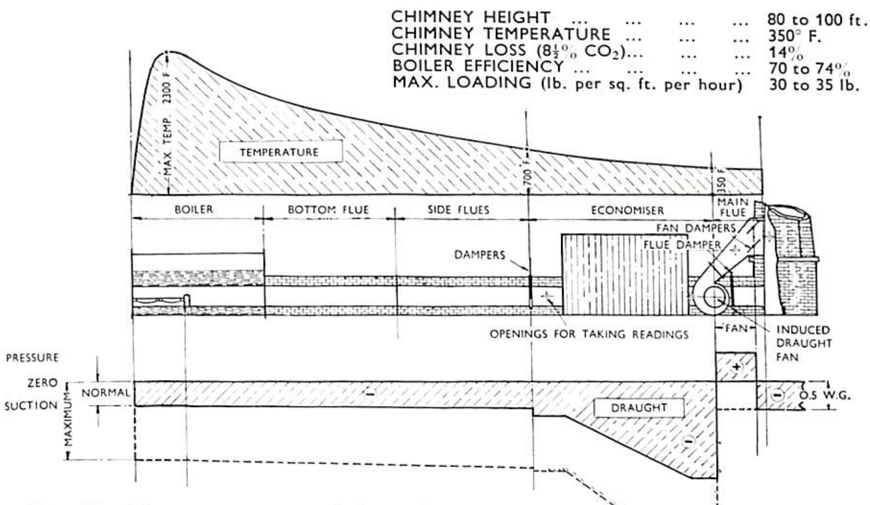



Fig. 35. Temperature and draught characteristics of a Lancashire boiler equipped with an induced draught fan driven at constant speed by, say, an A.C. motor coupled direct or through a V-rope drive.

The draught curve is the same, but as the fan is installed for maximum load the excess pressure at other loads has to be absorbed by partly closing dampers, either at its inlet or outlet.

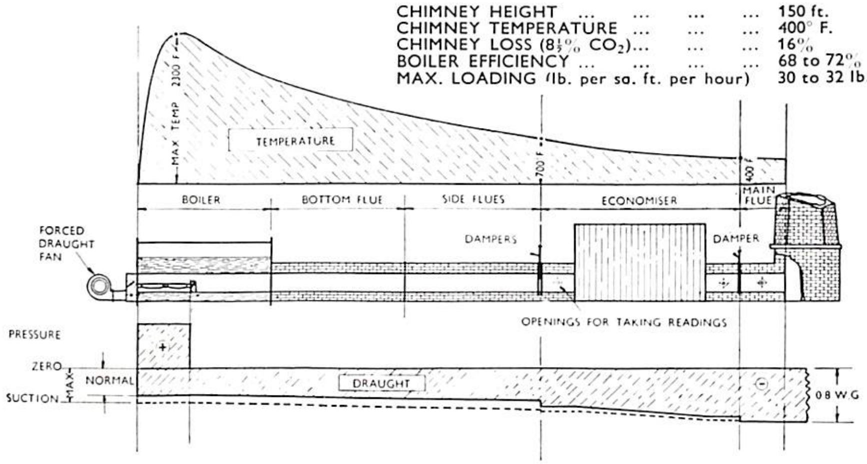



Fig. 36. Temperature and draught characteristics for the same boiler plant as in figs. 32 to 35 but with fan or steam jet forced draught.

The chimney temperature is again 400° F. and the chimney height 150 ft. because the draught conditions in flues and economiser are as for natural draught. The burning rate is greater, however, than with natural draught.

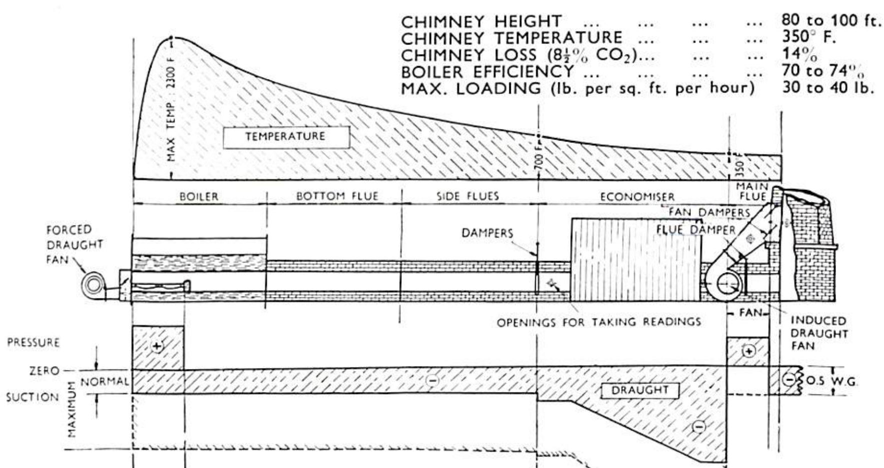



Fig. 37. Temperature and draught characteristics for the same plant as in figs. 32 to 36 equipped with balanced draught.

This enables high rates of burning to be used without the danger of "blow back" with forced draught, or flames being drawn off the fire with induced draught. The limit to the firing rate is when coal is blown off the grate, or when the furnace crown is brought down by stress due to a very high rate of heat transfer. For burning rates over 30 lb. per sq. ft. per hour, the furnace tube should be corrugated.

reduces the quantity of air discharged. The highest fan efficiency is claimed for vane control using constant speed A.C. squirrel cage motors, by which the output can be controlled down to 15 per cent of the maximum capacity. Wear on the vanes is small.

A two-speed motor drive is justified with vane control only when a plant may be required to operate at a reduced load for long periods. The fan is then operated at its maximum continuous rating at the low speed, with the vanes full open; that is, at maximum efficiency; the higher speed is used only to meet an overload.

The vanes may be operated manually through a worm gear, by a joy-stick, or automatically, as both damper and vane controls respond instantaneously to a control impulse with a change in loading.

*A draught-control indicator.* With all types of fans a definite horse power is required for the delivery of any volume of air, and when the temperature of the air or gases being handled is constant, the power used is a good guide to the volume of air or gases being delivered by a fan. This is a much better indicator than the pressure drop between inlet and outlet, which cannot be measured easily with reasonable accuracy. The current being used by the motor is indicated by an ammeter, the volume handled by the fan being constant when the ammeter reading is steady.

**The Effect on the Performance of Installing Induced or Forced Draught.**

The effects on the performance of a natural draught Lancashire boiler of the introduction of induced draught, of forced draught, of balanced draught, and of installing an economiser are shown in figs. 32 to 37.

**Shutting Down when both Forced and Induced Draught Fans are Used.**

When a boiler is being taken out of service the forced draught fan should be shut down before the induced draught fan. The induced draught fan is often left in service for some time after the boiler is taken off the range for cooling purposes. If this is done, care must be taken to ensure that the driving motor is not overloaded, as the cooler gases become the greater will be the load upon the fan with the dampers in a given position. The dampers should therefore be closed down gradually as the boiler cools.

# CHAPTER V

# GRATES

The purpose of a grate is to support the fuel to be burned in such a way that an adequate supply of air for complete combustion can be provided. Grates are given a plane surface so that neither ash nor clinker can lodge at any point upon them, and in their simplest form are built up of single bars, as shown in figs. 38a and 38b.

## GRATE CONSTRUCTION

There are three types of grates: stationary grates from which ash and clinker have to be removed by hand; moving or self-cleaning grates which convey burning coal through the furnace and eject ash and clinker at the back; and rocking bar grates which discharge ash through the bars into the ash pit instead of over the ends of the bars.

The design of firebars is based on experience, apart from the following general principles:—

(1) Firebars should have the least possible area in contact with the fire, and present the largest possible surface to the cooling effect of incoming air; they are therefore invariably made thin and deep.

(2) The resistance of the grate to the passage of air should be the minimum consistent with obtaining steady fuel bed conditions with different depths of various sizes of coal. For example, if the resistance is too low relative to the resistance of the fuel bed, relatively slight changes in thickness will tend to produce unsteady conditions, with the formation of holes through the bed.

(3) A small air surface enables a more uniform distribution of the combustion air over grate surfaces to be obtained, and restricts the influence of a pit in the fire. The quantity of particles of fuel falling through openings in the grate is also relatively small.

### Stationary Grates.

In addition to forming the grate on which the fuel rests, bars must secure a satisfactory distribution of air and be so designed that they are kept reasonably cool by the primary supply of air passing through them; that is, they must suffer the minimum possible damage by burning.

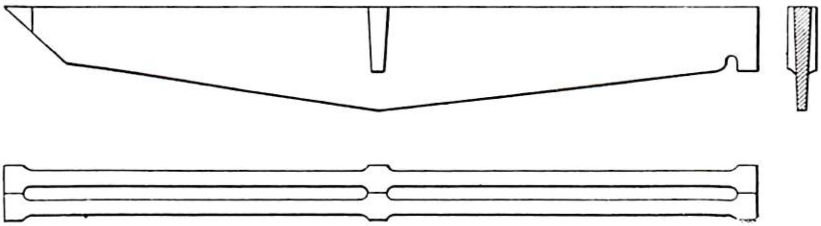


Fig. 38a. Air spaces between bars.

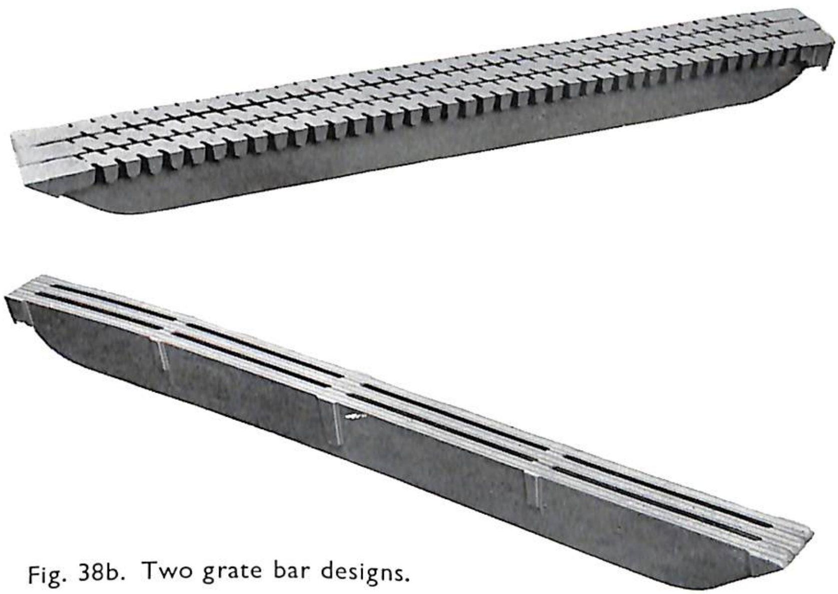


Fig. 38b. Two grate bar designs.

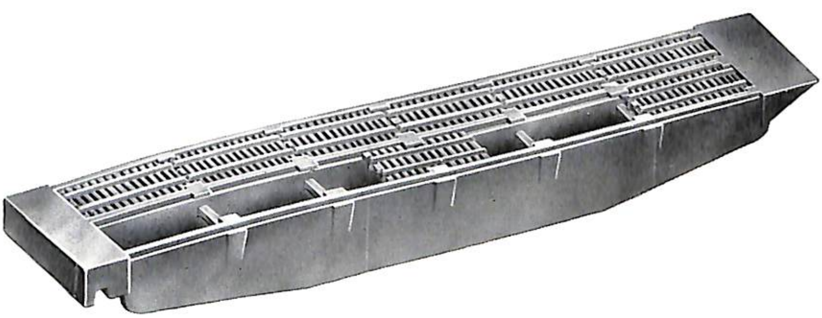


Fig. 39. A non-sifting grate bar for a stationary (fixed) grate. It consists of a frame into which small sectional tuyeres (air ports) slide to form a level grate with longitudinally raised ribs. It is only necessary to remove fine ash from under these grates at relatively long intervals.

If bars are given a high ratio of cooling to supporting surface, and the primary supply of air is adequate to prevent overheating at all loads, little damage will be done even when burning relatively low ash coals. A deep narrow bar meets these requirements, but the cooling surface is sometimes extended by casting ribs upon them.

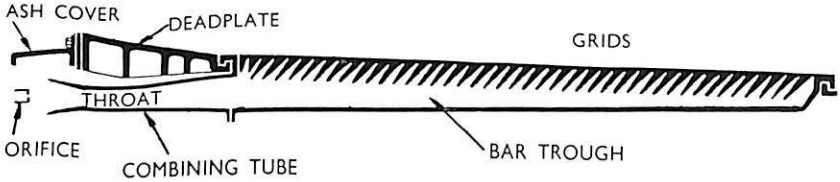



Fig. 40. A trough bar with the names of the various parts.

Fig. 41. A moving trough bar for steam-jet forced draught with renewable grids.

The width and spacing of the air openings is important. The maximum width permissible is governed by the size of coal to be used and the minimum by the fineness of distribution and the resistance desired from the grate

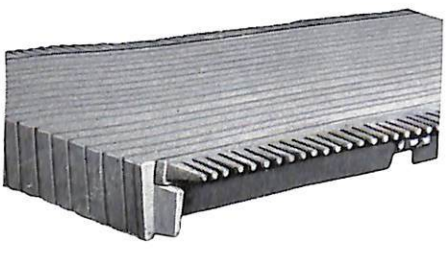


Fig. 42. Tooth side bars with extended teeth which are chipped to suit any irregularities or corrugations in the flue. These are used to complete moving bar grates.

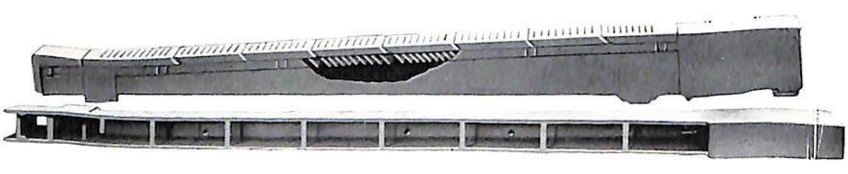


Fig. 43. A self-cleaning moving trough bar for fan-forced draught with renewable grids.

Many grates are formed of trough-shaped bars into which small interlocked groups of firebars are inserted. A stationary firebar of this class is shown in fig. 39, and trough bars similarly equipped in figs. 40 and 43.

Trough bars are used with forced draught and have the advantage of confining the air pressure, and hence possible leakage through a thin fuel bed, to limited areas of the grate. The relatively greater amount of metal in them means that more air is required to keep them cool, so that very often, and especially at low loads, all the air required for combustion must be supplied through them, and steam or water jet cooling provided for. Bars are sometimes made to overlap in such a way that air is directed at an angle into the fuel bed. This reduces riddlings, and is the principal feature of "non-sifting" grate bars. A method of assembling such units in a stationary grate is indicated in fig. 39. These are placed in a specially constructed frame which resembles the bar used with hand-fired grates. A low resistance to the air flow is claimed for this design. This is important with natural draught installations. It is also claimed that a layer of fine ash is retained between the ribs which prevents clinker adhering to the grate.

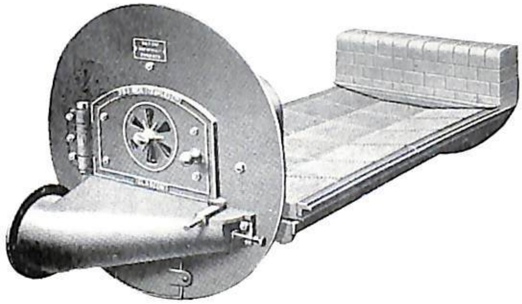


Fig. 44. The "Neil" retort furnace.
The hearth is formed of grate blocks perforated with a large number of venturi-shaped apertures. The underside of the grate is a totally enclosed air box from which the fan-draught is shut off automatically when the firedoor is opened.

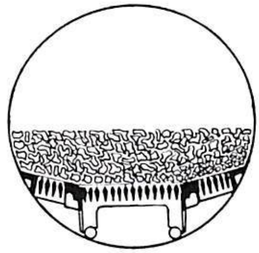


Fig. 45. A cross-sectional front elevation of the "Neil" retort furnace.

For even distribution of air the total cross-sectional area of the openings from a trough-shaped bar must not be greater than the cross-sectional area of the trough. Bridge pieces placed across the trough to support the grids tend to deflect the stream and interfere with distribution. When this occurs the ends of the grid become overheated and burn. Combustion is also affected. The placing of the air slots across the length of the bar, arranged so that a sudden change of direction is not necessary for flow into the fuel bed, avoids this difficulty.

A so-called retort furnace is shown in fig. 44. This has the form of a trough, the depth of fuel with a level bed being greatest down the middle. Volatile matter distilled from coal in the centre is subjected to radiation from the sides, an effect being obtained similar to that with side-firing. The units which form the grate have a large number of venturi-shaped air-holes in them.

**Self-cleaning Grates.**

The self-cleaning action of a moving grate is not due solely to the action of the bars, or to the slope they are given from front to back. The surface is stepped, curved or corrugated to obtain a vertical scissor-like movement sufficient to break up clinker, and assist the passage of air through the bed. The fuel bed is transported through the furnace 2 to 4 in. at a time. This is followed by the withdrawal of individual bars or groups of bars in turn to their original positions, the fuel bed being left in its new position. Ash and clinker are discharged with each backward motion of the bars. Generally, cams fitted to a steel shaft are made to thrust forward plain firebars of a narrow but deep section. In all designs the bars are moved forward together but they may be pulled back at intervals singly, or in interlocked groups. The interlocking of bars is preferably effected without the use of nuts and bolts, which would seize after a very short period, thus adding to the cost of maintenance.

A moving trough bar grate is shown in fig. 46. The action is effected through chilled cast iron cams mounted on a shaft, which engage with those on the trough bars (fig. 48).

Fig. 46. The "Proctor" self-cleaning bar grate.
The front end of each bar runs on a loose roller, and the rear on a fixed roller (fig. 47). The bars are operated by chilled cams threaded on a hexagon shaft (fig. 48). All the bars are thrust forward together but are returned in sections (fig. 49), thus giving them a powerful self-cleaning action.

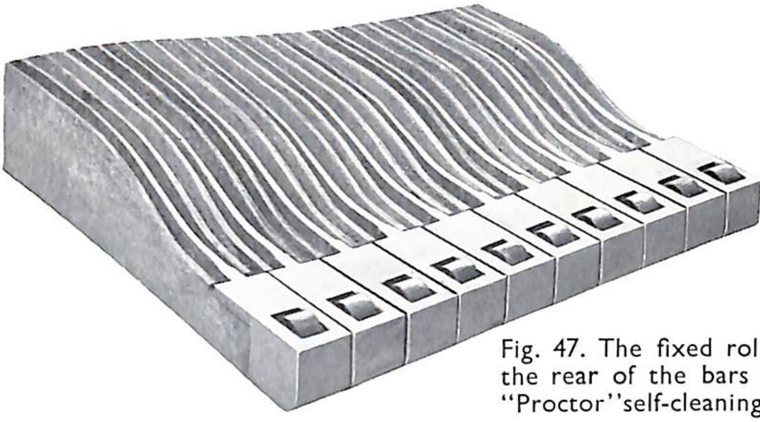


Fig. 47. The fixed rollers at the rear of the bars of the "Proctor" self-cleaning grate.

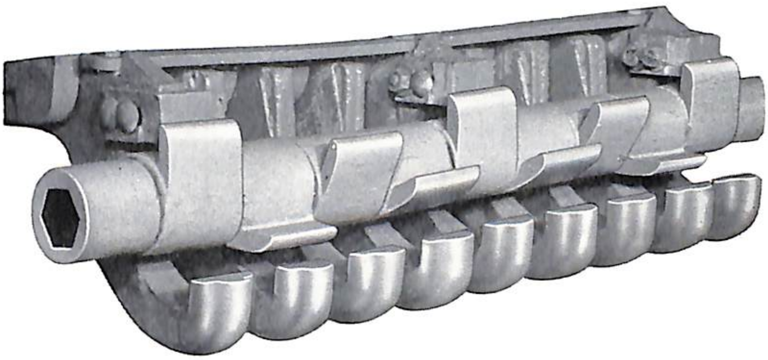


Fig. 48. The chilled cams mounted on a hexagon shaft for operating the bars of the grate shown in fig. 46.

The cam shaft is driven by an eccentric and rack wheel motion from the stoker driving shaft. The bridge is built 3 ft. 6 in. from the back bearer, through which a small quantity of steam is circulated for its cooling effect and then discharged under the grate.

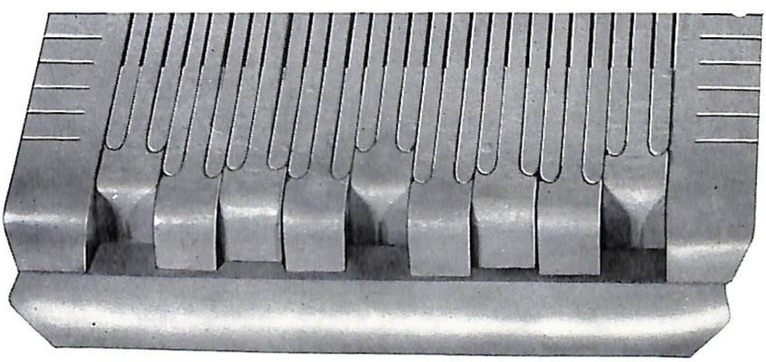


Fig. 49. The withdrawal of the bars in sections from the "Proctor" self-cleaning bar grate.

**Rocking Bar Grates.**

A rocking bar grate is shown in fig. 50. The components of the frame and the transverse bars are each interchangeable and reversible, self-locking without bolts or pins, and easily removable. The bars rest on pivots upon which they are rocked. The grate length may be varied by dummy bars (no

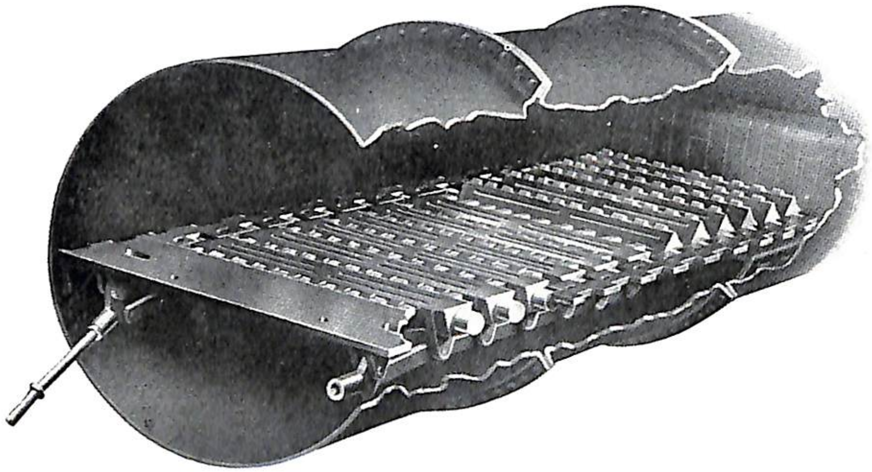


Fig. 50. A rocking bar grate with the right-hand bearer bar removed showing the rocking and cleaning operation at the rear section. The front and rear sections may be operated separately.

air slots), and the front and rear sections of the grate may be rocked independently. The movement is effected by hand with the aid of a steel bar which gives greater leverage. This is the only type of moving grate used with vertical boilers.

## THE STANDARD LENGTH OF GRATE

The length of grate of a Lancashire boiler is limited with hand-firing to an area which can be kept uniformly covered. The design ratio of grate area to heating surface is also based upon this factor. Mechanical stokers have therefore been designed to replace hand-firing under the same conditions. Ash and clinker are removed by hand to some degree in both systems, whether the grate is self-cleaning or not. The standard length of grate thus remains 6 ft., except for the smallest sizes (a boiler 24 ft. long, for example, being fitted with grates 5 ft. 6 in. long), and for chain and travelling grates.

## THE DISTRIBUTION OF AIR UNDER A GRATE

Two systems are in common use for the control of the distribution of air supply under the grates of Lancashire and vertical boilers.

In the first system, trough bars are used through which a "forced draught" passes to the grate, as shown in fig. 51. These divide the underside of the grate into compartments which extend from the front to the back of the

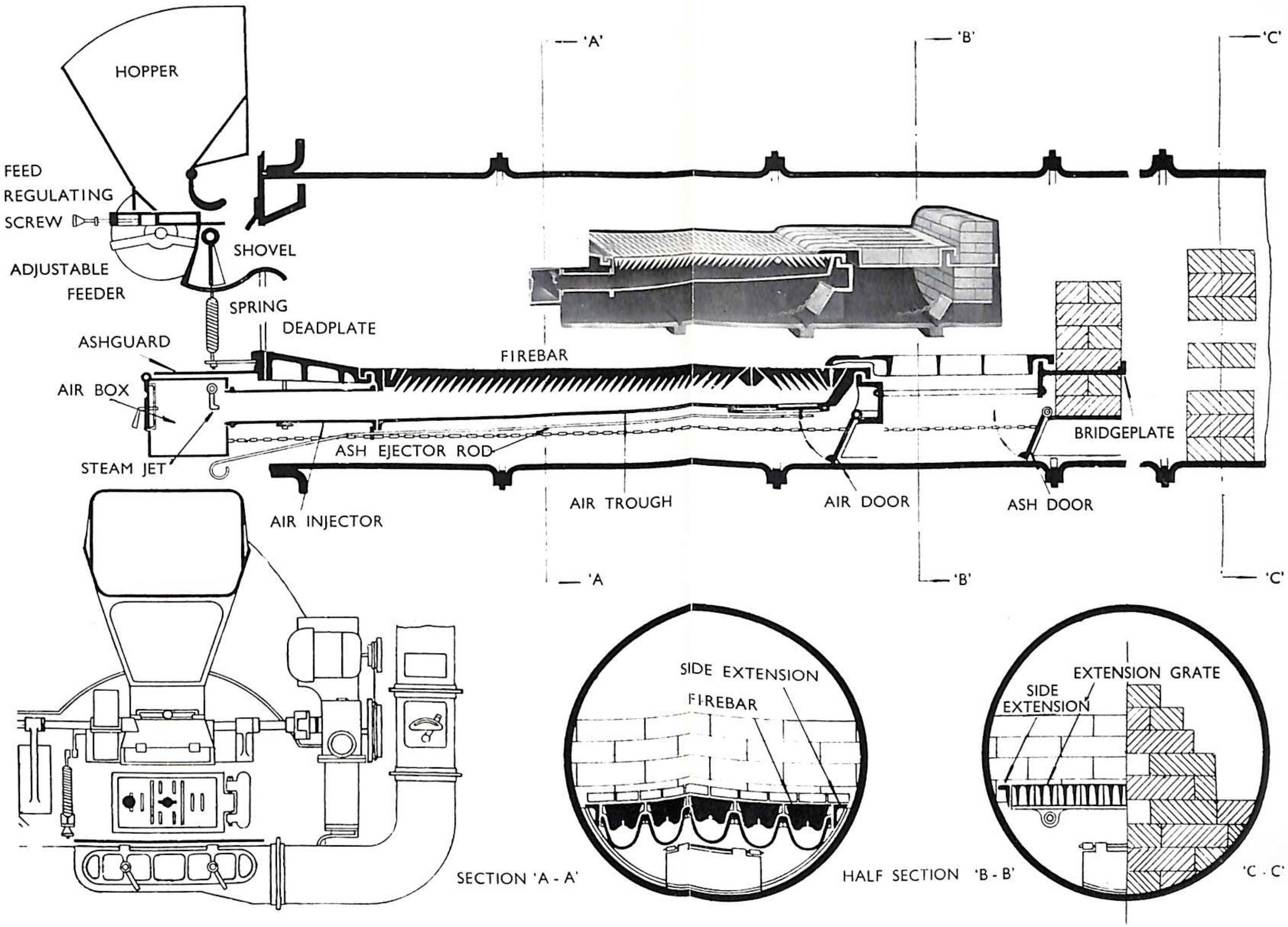



Fig. 51. The "Turbine" furnace.

The grate is built up of trough bars of a diminishing cross-sectional area to secure a uniform air pressure throughout their length. The draught in the troughs is fan-forced and as the bars are set at an easy angle in relation to the air flowing along the trough they have a relatively low resistance. Steam jets are provided for use in an emergency and to cool the bars. A number of bars at the rear are reversed to direct air against the normal direction of flow of the combustion gases in the furnace tube, thus promoting turbulence and more effective mixing. A secondary supply of air is provided at the front of the grate by keeping the first few bars clear of fuel. The air spaces allow only fine ash to fall into the troughs from which it may be removed through a shutter at the back. The grate is fired by hand or mechanically.

grate. The ash pit is open. Another way of obtaining this effect is to build up the grate from bars, as shown in fig. 53, which are fitted across the furnace. The apertures A then form continuous air tubes from which air passes into the fire through slots formed by the recesses B. Spigot and faucet joints

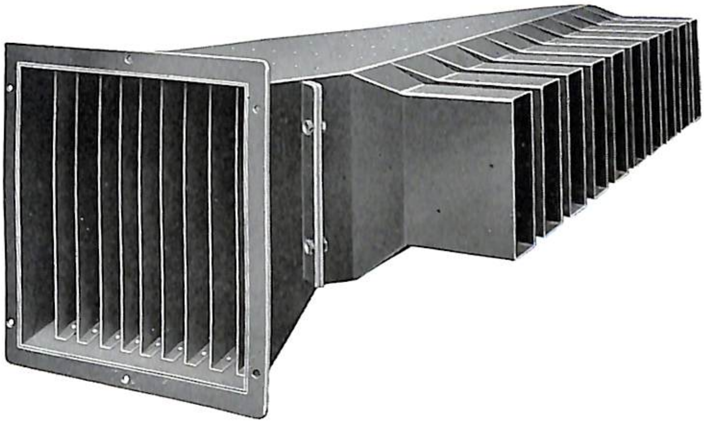


Fig. 52. A chamber divided to ensure a uniform distribution of air to trough bars. The ends of the trough bars (fig. 43) fit over the projecting sections.

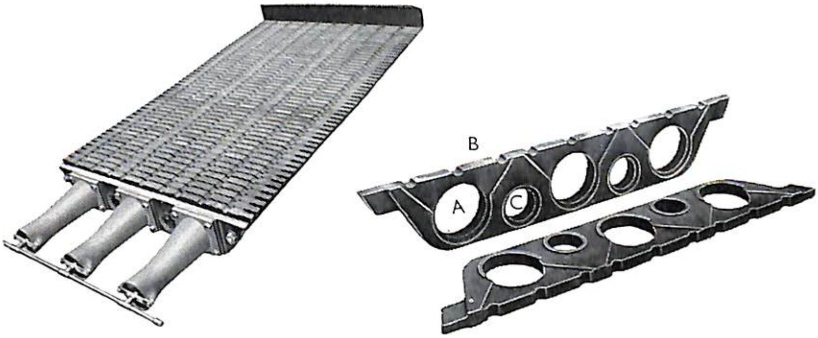



Fig. 53. A furnace constructed of firebars ($\frac{7}{8}$ in. thick) fitted across the furnace tube.

They are so designed that when put together they form a series of air ducts A, into which air is forced by steam jets. The spigot or faucet joints do not allow air to pass into the space under the grate.

prevent leakage to the ash-pit, and openings C provide a passage for a secondary supply of air to the firebridge. A grate of this type with fan draught is shown in fig. 54 and a grate constructed similarly for a vertical multitubular boiler in fig. 55.

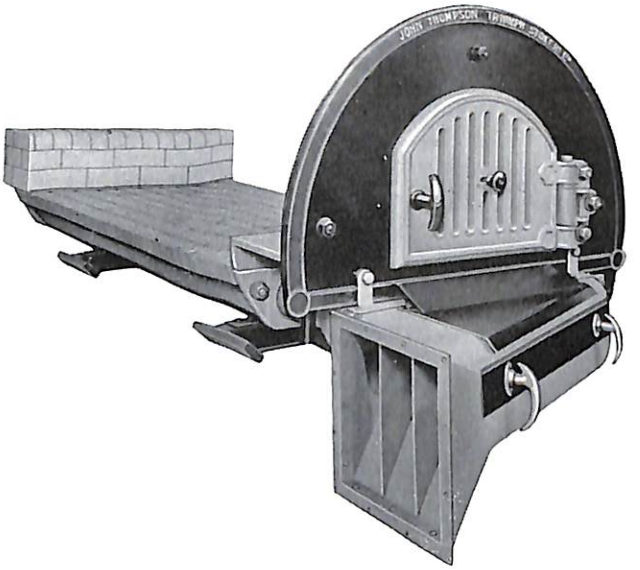


Fig. 54. A grate constructed as in fig. 53 with fan draught.

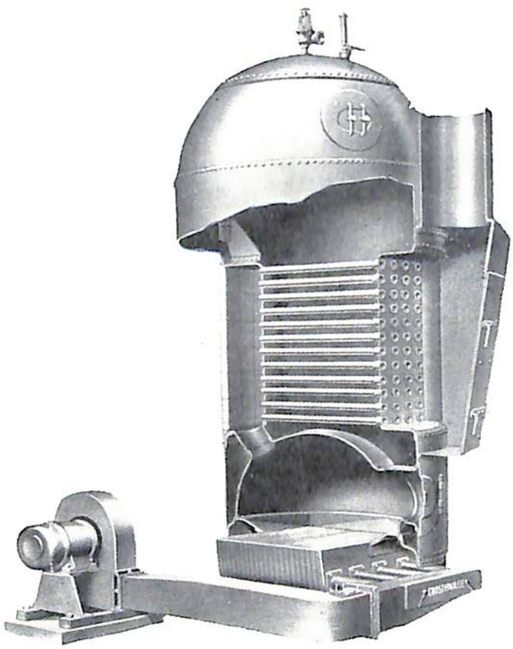


Fig. 55. A Crosthwaite cross-bar furnace of the type shown in fig. 53 applied to a vertical multitubular boiler with fan draught.

The grate is not fixed to or supported by the boiler, and is completed by cast iron deadplates with a protective firebrick ring.

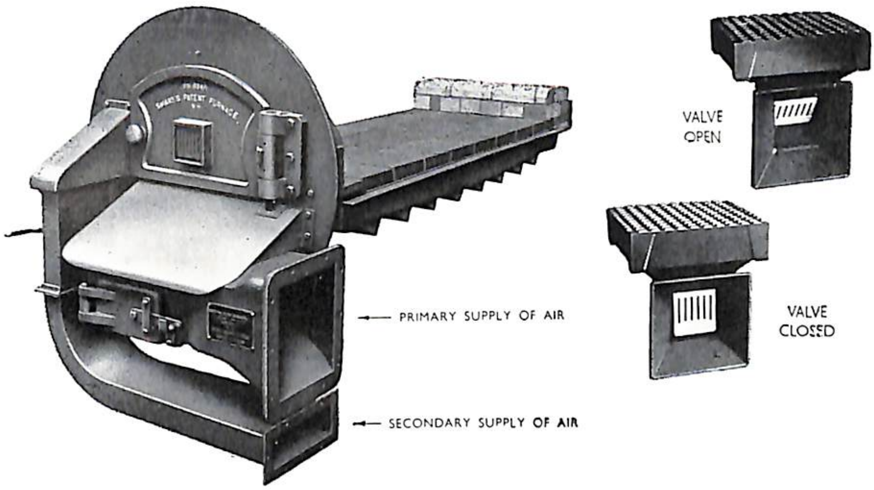



Fig. 56. A Doby-Smart grate.

This is divided by a unit construction into a number of rectangular compartments. Fan-forced draught discharges into a closed ash-pit and into a compartment around the firedoor from which a secondary supply of air is supplied over the fire. The supply over the grate is controlled by a separate damper, and the air supply is shut off automatically when the firedoor is opened, and restored when it is closed through an extension of the hinge pin which can be seen on the right-hand side of the door. The operation of the valve in the grate units is shown on the right. A similar valve is fitted in the firedoor to indicate by its position the draught over the grate.

The alternative system is to have the underside of the grate divided into a number of rectangular compartments with the ash-pit closed, as shown in fig. 56.

The surface of the units in fig. 56 is built up of a number of pyramids, each of which has an air-hole. These are tapered upwards towards the grate so that ash cannot lodge in them. An automatic air valve is included in each unit. This, it is claimed, allows only sufficient air to pass to keep the unit cool when there is no fuel upon it, but allows an increase in the supply of air, as the resistance of the fuel bed rises.

## COOLING GRATES

Steam-jets are used with some coals to cool the grate, lengthen the life of the bars, and prevent or reduce the formation of clinker. It is impossible to make a list of coals and say with what design of equipment or at what load the cooling of the grate may become necessary when burning them. The only warning that cooling has become necessary is an excessive formation of clinker and overheating of the bars.

It is not unusual to find a quantity of steam being used for this purpose as great as that required for a forced draught, which incidentally would have the same cooling effect. This is a costly way to cool a grate. In certain tests

1 per cent of the total steam generated lowered the temperature of the links of a travelling grate by 54° F. with a caking coal and 90° F. with a non-caking coal.

**The Control of "Under Fire" Steam-Jets.**

An arrangement of steam-jets under a grate is shown in fig. 40. When steam is used solely to obtain a cooling effect, the pressure has no practical significance, apart from the fact that the greater the pressure at the orifices the greater the quantity of steam delivered in a given time.

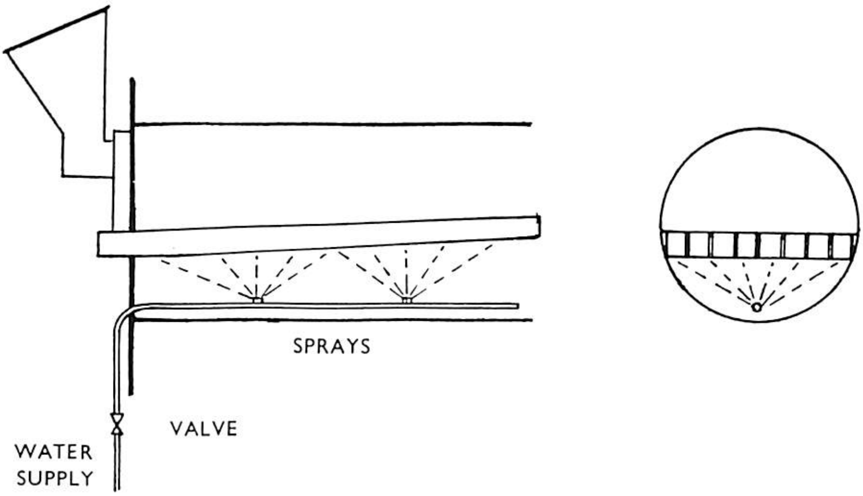



Fig. 57. An arrangement of water jets under the grate of a Lancashire boiler.

If a jet $\frac{1}{16}$ in. in diameter acquires a diameter of $\frac{3}{32}$ in., due to erosion, the quantity of steam supplied by it will have become four times as great. An accurately bored plate—an orifice plate—should therefore be fitted in the steam pipe to the jets, with a steam reducing valve, and a stop valve and steam pressure gauge before it, so that the quantity of steam flowing to the jets can be checked and controlled.

The amount of steam passing through an orifice may be calculated, using the formula:—

$$W = 51A(P + 15)$$

where W is the weight of steam in pounds per hour passing through a jet A square inches in area, at pressure P lb./sq. in. gauge. Alternatively, the figure for, say, 1 per cent of the normal steam load may be taken and a size of orifice chosen which will deliver this quantity at a relatively low pressure, say, 10 lb. per sq. in. gauge; the pressure and/or diameter of the orifice is subsequently increased only if this becomes necessary. The orifice in the plate should be checked periodically for erosion, and replaced when this becomes appreciable. Cooling with water jets, however, is more effective and less costly on all counts, and does not waste fuel.

**Cooling with Water.**

Heat amounting to 41 B.Th.U. is absorbed by 0.3 lb. of water as steam at atmospheric pressure raised to a temperature of 500° F. in passing through a grate; the same weight of water sprayed on to the underside of a grate to form steam, and then heated to 500° F., absorbs 386 B.Th.U. In addition to this greater cooling effect, water appears to break up clinker more effectively.

When a boiler is continuously operated at a moderate load it is seldom necessary to use either water or steam to cool the grates, but in intervals following periods on high load, when the primary supply of air has been reduced, and while a relatively high fuel bed temperature persists, cooling may become necessary. Water sprays are liable to become choked with dirt, and therefore require more supervision than steam jets. They are nevertheless to be preferred, and an arrangement is shown in fig. 57. Clean water is, however, essential and a filter should be fitted if necessary to ensure this.

**The Installation and Control of Water Jets.**

A design of water jet which has been found satisfactory is shown in fig. 58. The size shown will deliver 70 lb. of town's water per hour at a pressure of 20 lb. per sq. in. gauge.

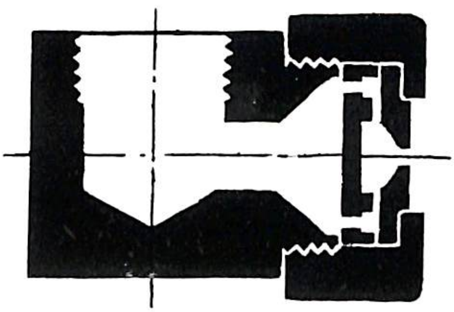


Fig. 58. A water jet $\frac{1}{2}$ in. B.S.P. thread, orifice $\frac{9}{16}$ in.
Constructional details are given in Fuel Efficiency Bulletin, No. 20, of the Ministry of Fuel and Power.

Water is particularly effective when applied to firebars of the open type. The atomisers are fixed into an arrangement of pipes which rest on the bottom of the furnace tube and are supplied with clean water at a pressure of about 20 lb. per sq. in. A flexible connection is made with the water main so that the jets can be withdrawn from the furnace tube at any time. Water jets have been found effective also with sprinkler stokers and trough bars. The sprays are placed beneath the troughs, as there is usually enough space between them to allow the atomised spray to reach the fuel bed.

Care is needed to prevent water dripping from the firebars on to the flue, arrangements being made to drain away any water that may accumulate. It is also necessary to ensure that the frame carrying the jets can be simply and easily replaced in its correct position relative to the grate.

**Cooling by an Insulating Layer of Ash.**

It is not possible to predict accurately the heat exchange between burning fuels, grate bars and combustion air, but the following points are clear:—

(1) The top surfaces are heated by contact with the burning fuel bed.

(2) The side surfaces are heated by radiation from the undermost layer of the fuel bed, and less than 15 per cent of the heat radiated by the fire penetrates through the openings in the grate to the ashpit.

Since the heating of bars is principally by contact with the fuel bed, the most effective means of keeping them at a reasonable temperature would be an insulating layer of porous material with low heat conductivity. Unmolten ashes meet this need, hence the soundness of the practice of forming grooves or recesses in the top surfaces of firebars which will hold such a layer. Gratebars with and without a permanent ash layer are shown in figs. 59 and 60.

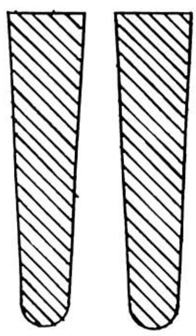


Fig. 59. Simple grate bars in section.

Fig. 60. Grate bars with permanent insulating ash layer.

In certain tests, the temperature on the top of bars without a permanent ash layer ranged from 400° C. (a cleaning period) to 1,050° C. with coal with an ash of low fusion point fired at the rate of 40 lb. per sq. ft. per hour. The temperature of a bar with a permanent ash layer under approximately the same conditions varied from 680° to 800° C. The temperature at the bottom of the bars in this latter test varied from 320° to 420° C.

The maximum temperature was reached some time after cleaning the fire, when fresh burning coal covered the bars. This dropped gradually as a layer of clinker formed. At the highest temperatures with the ungrooved bar the ash was molten along with the firebars, clinker was difficult to remove and the bars were severely damaged. With the grooved bars the temperatures were not low enough to prevent slight damage to the top surface by the aggressive clinker.

**Grate Cleaning and Mechanical Stokers.**

The cleaning of fires is the most strenuous and exhausting work a fireman has to do. However strong he may be, this work becomes almost unendurable when grates require cleaning more than once in every $1\frac{1}{2}$ hours. Low-

pressure steam is therefore often supplied under boiler grates to reduce the formation of clinker and extend the cleaning period. When a boiler is fired mechanically, however, and self-cleaning grates are fitted, it is necessary only to clear the ash-pit, and this at relatively long intervals. This makes it possible to use coals with relatively high ash and fines contents which are being increasingly supplied nowadays for steam raising, without the work becoming too arduous.

# CHAPTER VI

# COKING AND SPRINKLER STOKERS

There are four types of mechanical stokers:—

(1) coking;

(2) sprinkler mechanisms with stationary or moving grates;

(3) chain grate; and

(4) underfeed.

These may be divided into two classes. One in which coal is fed from above grate level, known as overfeed stokers; and the other in which coal is fed from below grate level, known as underfeed stokers. This division must not be confused with overfeed and underfeed burning.

The original coking stoker was invented by William Brunton in 1822, the object being to coke the coal before it reached the grate, thus making it easier to burn the volatile matter and so prevent black smoke. The first sprinkler, invented by John Stanley, also in 1822, was designed to sprinkle coal evenly over a stationary grate and maintain a uniform depth of burning fuel.

These machines have several features in common (figs. 61a and 61b). The supply of coal is arranged in a hopper in front of each furnace tube. The coal feeding mechanism is fitted into a small horizontal chamber below the hopper, and consists of a slow-moving ram which travels a few inches backwards and forwards. On the backward stroke, an opening is disclosed in the base of the hopper, a charge of coal falls through and is displaced on the forward stroke into a second chamber by the ram. The difference between the two is in the second chamber. In the coking stoker, fig. 61a, coal is pushed forward on to a horizontal plate within the furnace, known as the top coking plate, where it is heated and partly coked before being displaced by a new charge to fall on to the front of a moving grate. In the sprinkler, fig. 61b, the second chamber is outside the furnace, and has within it a rotating arm or spring-loaded shovel by which coal is spread over the fire-bed. The rate of feed is adjustable in both designs. The first sprinkler was used with a stationary grate, but nowadays they are also used with moving or self-cleaning grates.

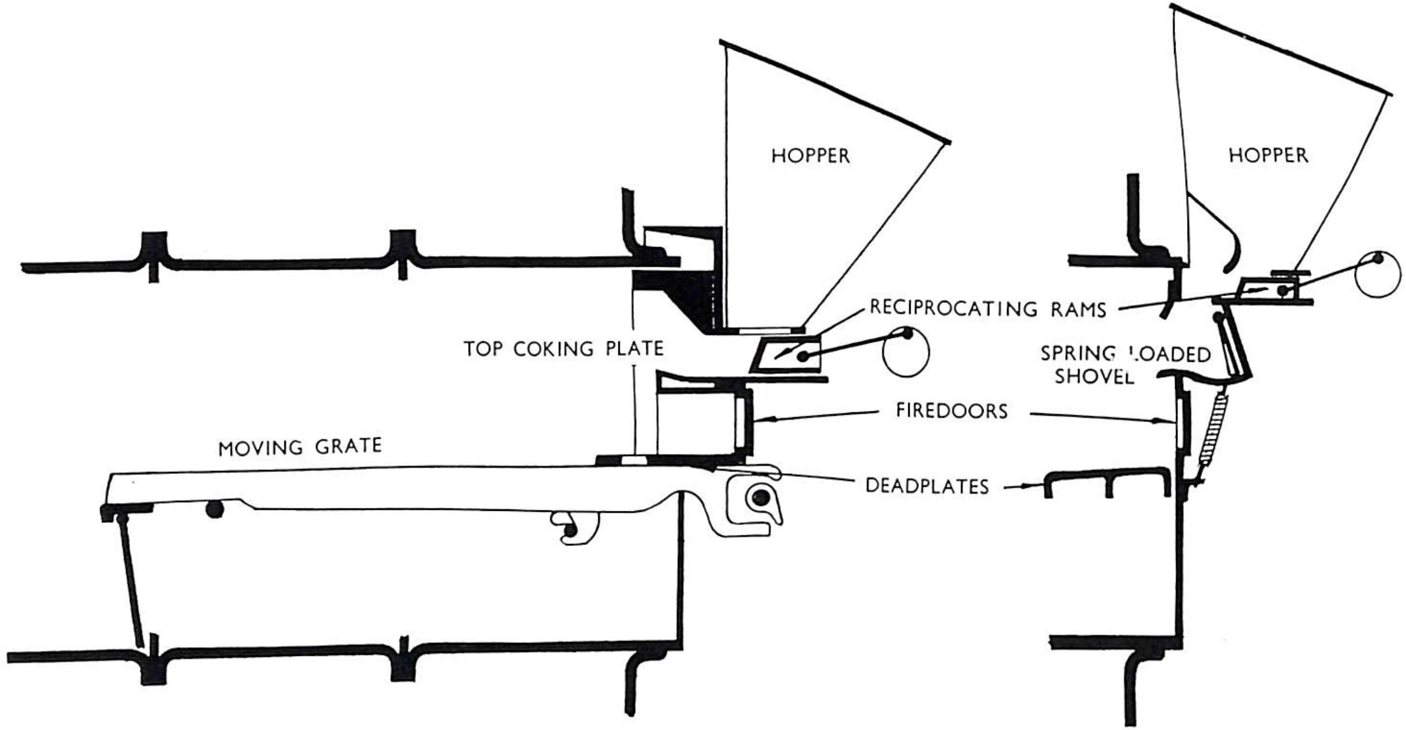



Fig. 61a. A coking stoker.

Coal is pushed forward on to a horizontal plate **within** the furnace, known as the top coking plate, before being displaced by a new charge to fall on to the front of a moving grate. The rate of coal feed is adjustable.

Fig. 61b. A sprinkler stoker.

Coal is pushed forward on to a feeder plate **outside** the furnace and is projected into the furnace by a spring loaded shovel on to a stationary grate. The rate of coal feed is adjustable.

Whilst a sprinkler is used to spread coal over any type of grate, the moving grate is an essential part of a coking stoker. The original invention of Brunton included the deadplate, the slow-moving reciprocating ram, a driving shaft to thrust all the grate bars forward together and dip them slightly on the return action to leave the fire stationary in its forward position. A closed ash-pit was included, and there was an arrangement by which air spaces were restricted at the deadplate, opened out in the middle and again restricted at the back. There have been many mechanical improvements since the original design, but the principle remains unchanged.

## COKING STOKERS

With coking stokers, coal is fed on to the front of a moving grate by way of a coking plate located above the firedoor. This method is most effective with medium coking coals, as strongly coking coals tend to form large masses of coal which do not readily break up of themselves. Free-burning coals do not cake and are not suitable for use with this machine. A coking stoker with a top coking plate is shown in fig. 61a. This is fitted with a normal firedoor through which attention may be given to the fire-bed should a too highly caking coal be used. This typifies the **"Bennis,"** the **"Triumph"** and the **"Hodgkinson"** machines of this class.

Burning coal falls from the coking plate on to the front of the grate and is moved by it step by step towards the back, where ash and clinker are discharged. The grate level is invariably across the full width of a circular flue, fed from a relatively narrow plate placed at a higher level. Partially coked coal thus tends to pile up in the middle of the grate and leave the sides thinly covered.

This is overcome to a certain extent by reducing the forward motion of the side bars of the grate relative to those in the centre, and by casting a V-shaped projection in the centre of the coking plate to thrust the coal towards the sides. This is an improvement on a flat plate, although large pieces still tend to fall to the sides and burn away more quickly.

Uneven distribution does not occur to the same extent when the coking plate is made proportionately wider and placed lower in the furnace tube as in the **Hodgkinson Low Ram Coking Stoker,** fig. 62.

Steam-jet forced draught is not normally employed with coking stokers, nor is fan-forced draught used with them as a class except with the Doby coking stoker, a design in which the ram feeder extends across half the width of the grate at grate level, distribution of coal being effected systematically over the whole grate by the action of the ram. In the **Bennis "Aries" Semi-Coking Stoker,** shown in fig. 63, the ram is at grate level, extends the full width of the furnace, and is attached to the reciprocating grate. The burning coal is carried forward by the motion of the firebars, and a stationary deadplate resists any tendency of the bed to move backwards as the firebars and ram are returned to complete the cycle of operations. Different rates of

Whilst a sprinkler is used to spread coal over any type of grate, the moving grate is an essential part of a coking stoker. The original invention of Brunton included the deadplate, the slow-moving reciprocating ram, a driving shaft to thrust all the grate bars forward together and dip them slightly on the return action to leave the fire stationary in its forward position. A closed ash-pit was included, and there was an arrangement by which air spaces were restricted at the deadplate, opened out in the middle and again restricted at the back. There have been many mechanical improvements since the original design, but the principle remains unchanged.

## COKING STOKERS

With coking stokers, coal is fed on to the front of a moving grate by way of a coking plate located above the firedoor. This method is most effective with medium coking coals, as strongly coking coals tend to form large masses of coal which do not readily break up of themselves. Free-burning coals do not cake and are not suitable for use with this machine. A coking stoker with a top coking plate is shown in fig. 61a. This is fitted with a normal firedoor through which attention may be given to the fire-bed should a too highly caking coal be used. This typifies the **"Bennis,"** the **"Triumph"** and the **"Hodgkinson"** machines of this class.

Burning coal falls from the coking plate on to the front of the grate and is moved by it step by step towards the back, where ash and clinker are discharged. The grate level is invariably across the full width of a circular flue, fed from a relatively narrow plate placed at a higher level. Partially coked coal thus tends to pile up in the middle of the grate and leave the sides thinly covered.

This is overcome to a certain extent by reducing the forward motion of the side bars of the grate relative to those in the centre, and by casting a V-shaped projection in the centre of the coking plate to thrust the coal towards the sides. This is an improvement on a flat plate, although large pieces still tend to fall to the sides and burn away more quickly.

Uneven distribution does not occur to the same extent when the coking plate is made proportionately wider and placed lower in the furnace tube as in the **Hodgkinson Low Ram Coking Stoker,** fig. 62.

Steam-jet forced draught is not normally employed with coking stokers, nor is fan-forced draught used with them as a class except with the Doby coking stoker, a design in which the ram feeder extends across half the width of the grate at grate level, distribution of coal being effected systematically over the whole grate by the action of the ram. In the **Bennis "Aries" Semi-Coking Stoker,** shown in fig. 63, the ram is at grate level, extends the full width of the furnace, and is attached to the reciprocating grate. The burning coal is carried forward by the motion of the firebars, and a stationary deadplate resists any tendency of the bed to move backwards as the firebars and ram are returned to complete the cycle of operations. Different rates of

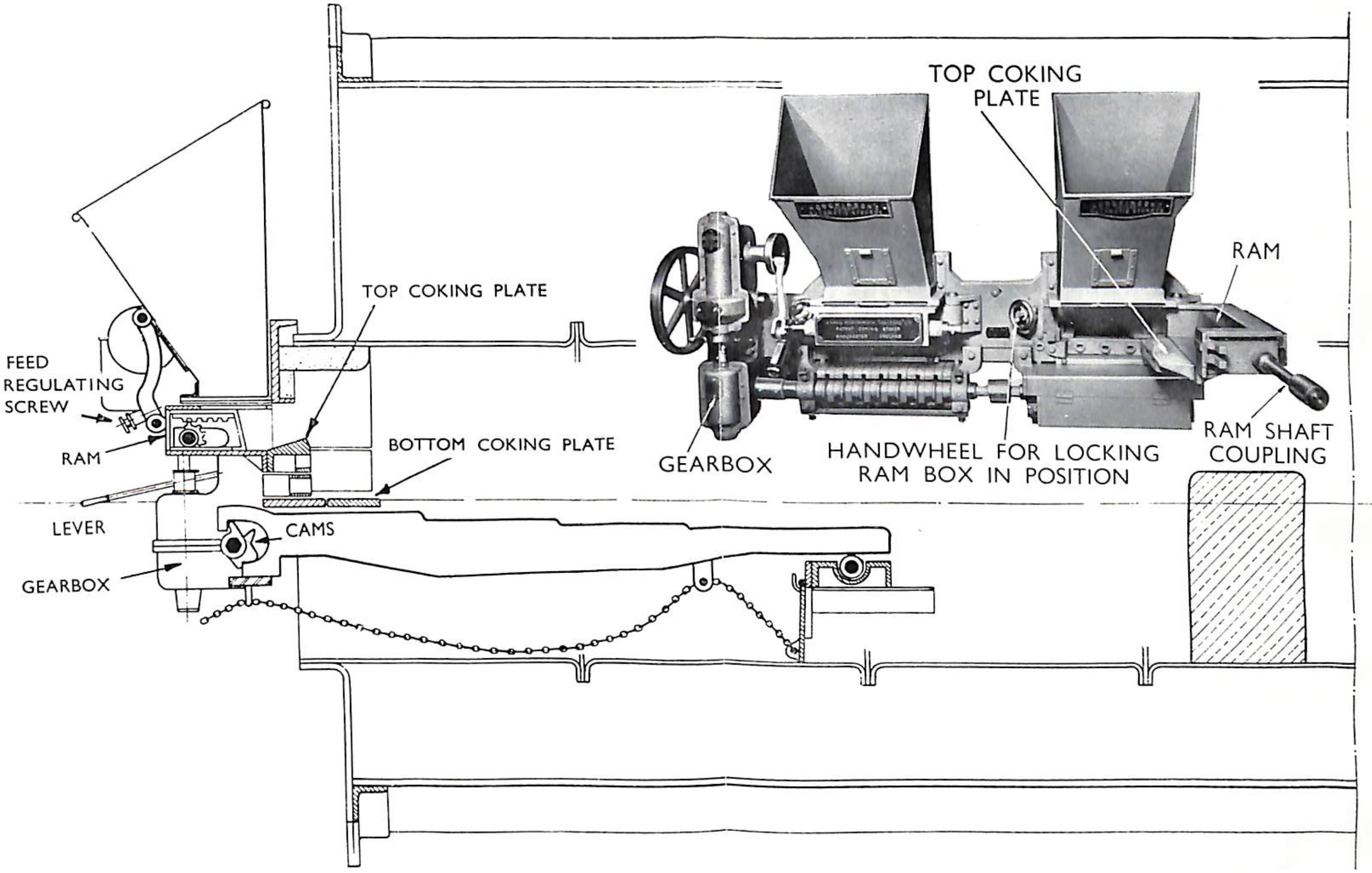



Fig. 62. The "Hodgkinson" low ram coking stoker.

This is so called because the reciprocating ram which pushes coal from the coking plate on to the grate is close to the grate. The lower a ram is set in a circular flue, the wider the ram which may be installed, and the wider the ram the more uniform and effective the spread of coal across the grate. This reduces the thickness of the firebed at the front, and allows a more uniform distribution of air. Coals with a higher percentage of fines can be used than with "high" ram coking stokers. In this design the ram takes the place of the firedoor, the ram and ram box swinging outwards from underneath the hopper, after the coal supply has been cut off at the base of the hopper by a sliding damper. This feature is shown in the inset, the drive in this instance being by V-belt from an electric motor through two gear boxes, one operating the adjustable reciprocating ram and the other the moving grate. When natural draught is inadequate it is augmented by induced draught.

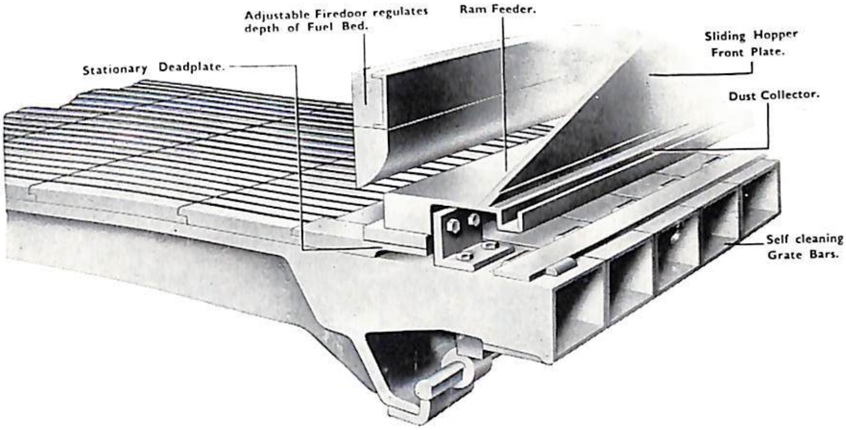



Fig. 63. The "Aries" semi-coking stoker.

The large hopper receives coal by hand or from an overhead bunker, elevator or conveyor. The fuel falls by gravity on the ram feeder plate at fire bed level. A ram attached to the reciprocating grate moves the fuel forward over a stationary deadplate. The reciprocating motion of the fire bars then carries the fuel forward step by step across the full width of the grate, and the stationary deadplate resists the tendency of the fuel bed to move backwards when the fire bars and ram are returning to complete the cycle of operations. Adjustments to the thickness of the fire bed are made by raising or lowering the firedoor.

burning are obtained by varying the depth of the fuel, by raising or lowering the firedoor, and also by varying the speed of the grate, as with chain and travelling grate stokers.

**The "Niagara-Thornton" Semi-Coking Stoker** is another design of this type. This has the coal feed also at grate level, and an adjustable fuel bridge or guillotine door with a refractory lining, to regulate the thickness of the fire. Features in this design are that the coking plate is in sections and air is kept from the fuel bed until it has been effectively ignited; it is made with two steps to ensure a positive forward movement of the coal, and travels forward with the bars and returns with the last bars to be withdrawn; the part of the deadplate nearest the grate is sloped towards the grate to ease its withdrawal.

The grate surface has renewable air ports or tuyeres threaded on to the supporting bars. These enable the surface to be modified to suit different classes of coal, and only tuyeres damaged by heat need be replaced. The cams which operate the grate, and with it the coal feed, are driven hydraulically. The length of stroke of the firebars is adjustable from zero to 3 in. The advantages claimed for the hydraulic drive are silent operation; automatic release from overload; absence of clutches, springs or gears; ease of lubrication and absence of wear.

Fan draught is fitted in these new designs as the normal draught equipment. This allows the air rate to be increased, and therefore a wider

variation in grate speed than would be otherwise possible. The original coking principle is thus fully attained mechanically, but the addition of fan draught is an advance beyond this, and invites comparison of the performance of these new types of stoker with that of chain or travelling grates also fitted with fan draught, with the same grades of coal. It is therefore convenient to refer to them as a distinct type, and to call them semi-coking stokers.

## SPRINKLER MECHANISMS: GENERAL

A sprinkler stoker consists essentially of two parts; a sprinkler feed mechanism and a gear unit; and may be used with a stationary grate, or with a moving self-cleaning grate, and with fan-forced draught.

Coal may be sprinkled over a stationary grate by a rotary sprinkler (see figs. 64 and 66) or by a spring-loaded swinging shovel (figs. 68 to 81). Cleaning of the fire is by hand.

A spring-loaded shovel with three or four throws of different length only is used with a moving grate. In this application the maximum length of throw is pre-set so that coal is not spread over the full length of a grate, a suitable distance at the rear being reserved for the completion of burning off before the ash is discharged over the end of the bars (see fig. 77). In one design the length of the three throws is the same, simply to the front of the grate. This combination of sprinkler mechanism with a moving grate and fan draught creates a distinct design of a sprinkler stoker, which virtually achieves the same mechanical result as semi-coking stokers, or chain and travelling grates.

## SPRINKLER MECHANISMS: THE ROTARY TYPE

**The "Niagara" Sprinkler Mechanism** shown in fig. 64 is in this class and is used with a stationary grate. Coal flows from a hopper on to a plate in front of a reciprocating ram, which delivers coal at a pre-set rate to a rotary distributor (fig. 65). The blades are held in position by centrifugal force, and as they are free to swing, large pieces of coal or foreign matter cannot jam the mechanism. The distributor is rotated at a steady speed, and the quantity of coal fed to it is pre-set by adjusting the distance traversed by the reciprocating pusher during each revolution of the distributor. The distance the coal is thrown is determined by an adjusting plate. These actions of the stoker are operated from the same motor-drive.

**The "Neil" Sprinkler Mechanism** is a rotary feeder (figs. 66 and 67) and is also used with a stationary grate. In this design, coal is spread uniformly over the grate by double-bladed impellers of cast steel mounted on a shaft supported by ball-bearing plummer blocks. In place of the usual reciprocating ram feeder there is a rotor, the ratchet drive of which may be set to give one of five rates of feed, ranging from zero to 50 lb. per sq. ft. of grate per hour. (The range of adjustment on the ratchet is five teeth.) These actions are synchronised and operated from the same drive. (See fig. 66, also fig. 89, for details of a ratchet drive.)

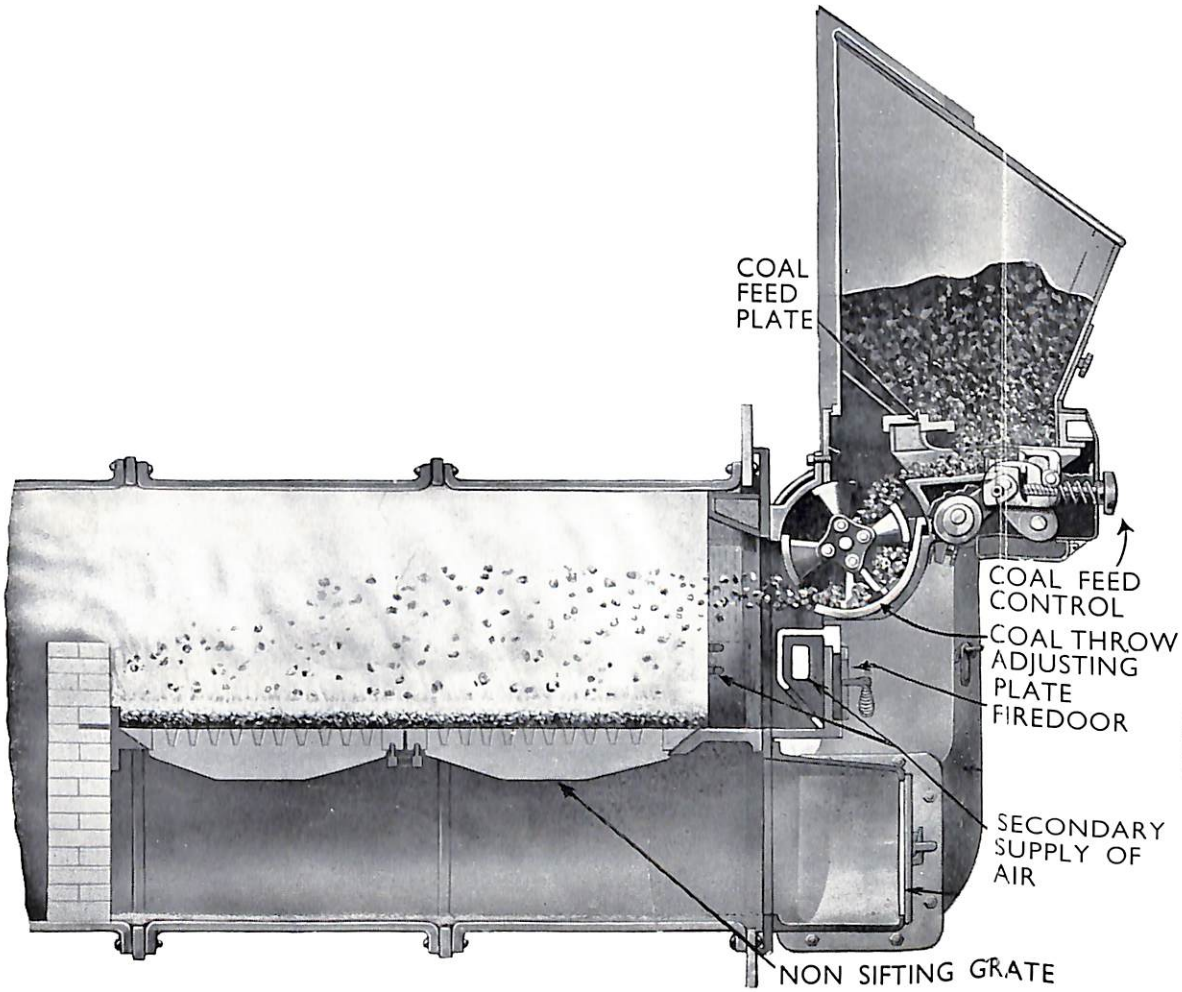



Fig. 64. The "Niagara" sprinkler stoker with fan-draught.

The coal distributor is rotated at a speed of from 250 to 400 r.p.m. The blades pick up the coal as it is fed on to the adjustable fuel throw plate by the slow backwards and forwards movement of a stepped feed plate. The quantity of coal fed (up to 15 cwt. per hr.) is governed solely by the distance moved by this plate, and this is adjusted by the fuel knob at the front.

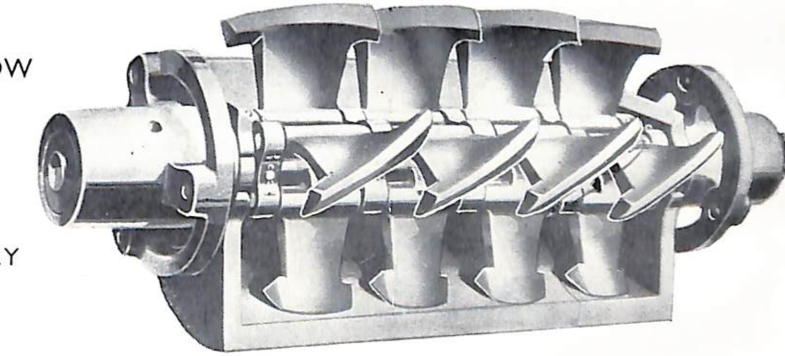
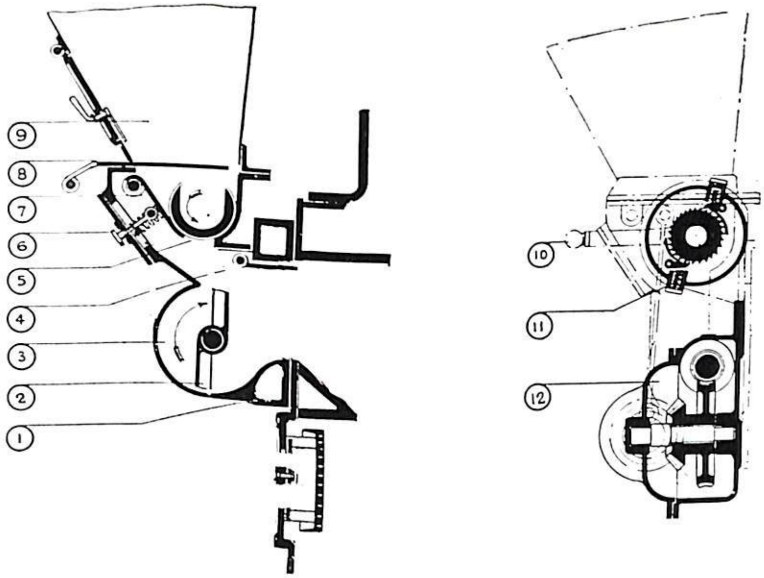


Fig. 65. Coal distributor blades for the "Niagara" sprinkler stoker.

The rows of blades are adjusted to scatter the coal first to the right and then to the left and are held in their correct positions when in operation by centrifugal force. An obstruction, such as a large lump of coal or stone, causes the blades affected to swing back on their pivots, the next set sweeping the obstruction into the furnace. These blades are practically indestructible.




1. Water panel.
2. Impeller.
3. Stoker casing.
4. Deflector.
5. Feed rotor.
6. Feed regulator control.
7. Feed regulator.
8. Cut-off valve.
9. Hopper.
10. Feed control handle.
11. Ratchet feed mechanism.
12. Gear box.

Fig. 66. The "Neil" rotary sprinkler stoker.

This stoker is built upon a rectangular hollow water-cooled panel suspended on swivel brackets from two studs fixed to the boiler shell. The furnace front is protected by air-cooled baffles or may be lined with firebrick. The gear box is oil-tight and dustproof. The feed motor may be adjusted to give five different rates of feed from zero to 50 lb. per sq. ft. per hour. A deflector plate is fitted inside the casing to suit the length of grate, and a spring-loaded feed regulator control prevents large coal or foreign matter from damaging the machine.

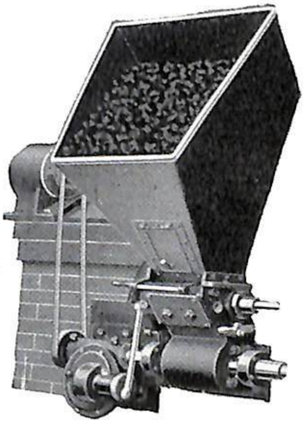


Fig. 67. A view of the "Neil" rotary sprinkler stoker showing a $\frac{3}{4}$ horse power motor mounted on an adjustable slide rail bracket, with a V-belt drive to the gear box, through which both the impeller shaft and the feed motor are driven. This is fitted to the retort furnace (fig. 44) with fan-forced draught.

## SPRINKLER MECHANISMS: THE SWINGING SHOVEL TYPE

**The "Doby" Sprinkler Mechanism** (figs. 68 and 69) is used with the stationary grate shown in fig. 56, and has three principal moving parts—an adjustable feed ram by which the amount of coal fed per cycle is determined; a spring-loaded shovel, actuated by six adjustable tappets which determine the angle and distance the coal is thrown; and a coal release gate or deflector which operates to deliver coal when the shovel reaches an appropriate position.

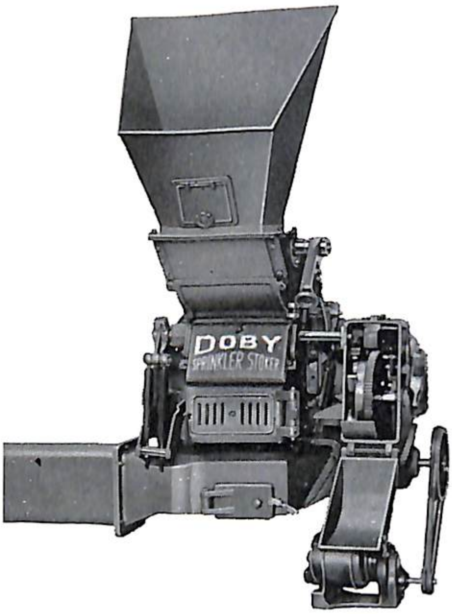



Fig. 68. A view of the "Doby" sprinkler stoker fitted to the stationary grate shown in fig. 56 with fan-forced draught.

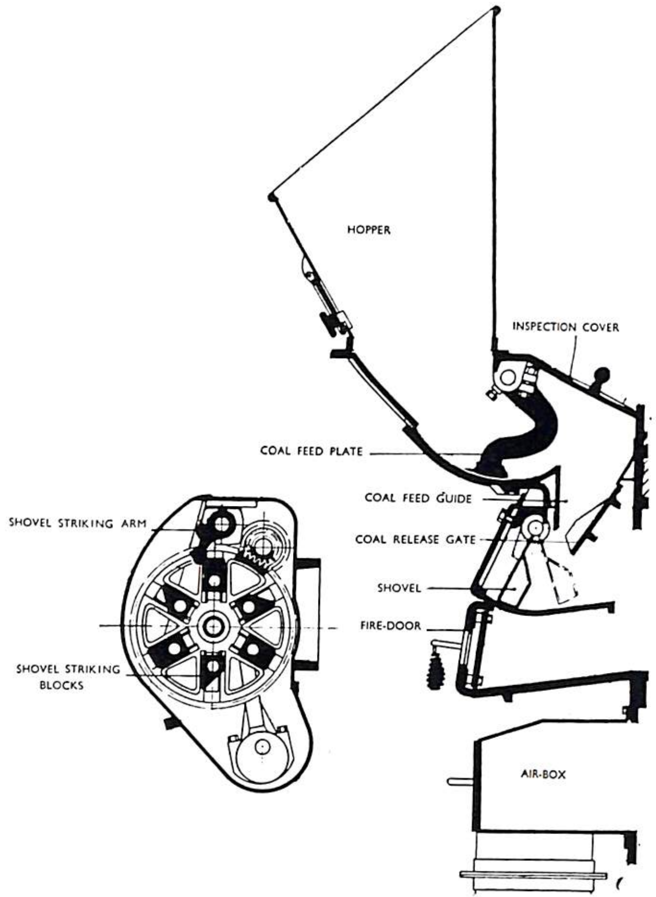
The impellers in the rotary type remain clear of the stoker casing when rotating. Wear is therefore at a minimum. Swinging shovels, on the other hand, have to be fitted to the feed plate over which they pass, or fines may pack up behind them and jam the mechanism—hence the need for easy access to them.

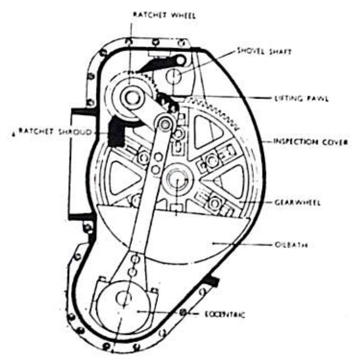
**The "Proctor" Sprinkler Mechanism** with a moving grate is shown in figs. 70, 71 and 72.

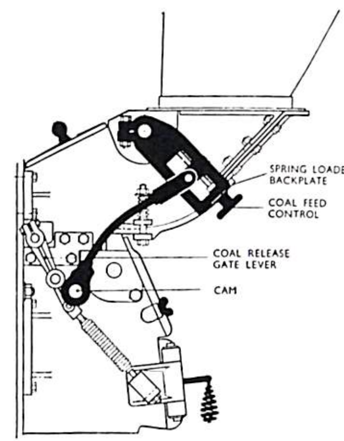
The drive and the power required with this mechanism illustrates general practice and is by a single- or two-speed vertical spindle motor of 1 h.p. This is connected to the main driving shaft by a slip coupling and worm reduction gear to give a speed of $6\frac{1}{2}$ r.p.m. when using the single-speed motor, or $4\frac{1}{2}$ and $6\frac{1}{2}$ r.p.m. using a two-speed motor. The slip coupling protects the machine against damage should an obstruction cause a stoppage. A method of adjustment is provided with which to take up wear of the fibre discs of the coupling. Alternatively, the drive may be by a 1 h.p. geared motor with a final speed of 100 r.p.m., then through a $\frac{7}{8}$-in. V-belt with four cone pulleys, worm reduction and bevel gears, to give speeds from

Fig. 69. Sectional views of the "Doby" sprinkler mechanism.

This has three moving parts: a feed ram which pushes coal from the base of the hopper into a chamber, the outlet of which is closed when the spring loaded shovel is being swung back to its striking position. The coal is then released through this gate to fall in front of the shovel, which projects it into the furnace after the gate has been closed. This prevents any building up of fines on the deadplate. These actions are synchronised, and each cycle delivers a preset quantity of coal into the furnace at intervals regulated by a control lever. The distribution and distance of each throw of coal is determined by the positioning of six cams upon a cam wheel. These have differing contours which vary the angle of throw across the width of the grate, and so assist the even distribution of the fuel.



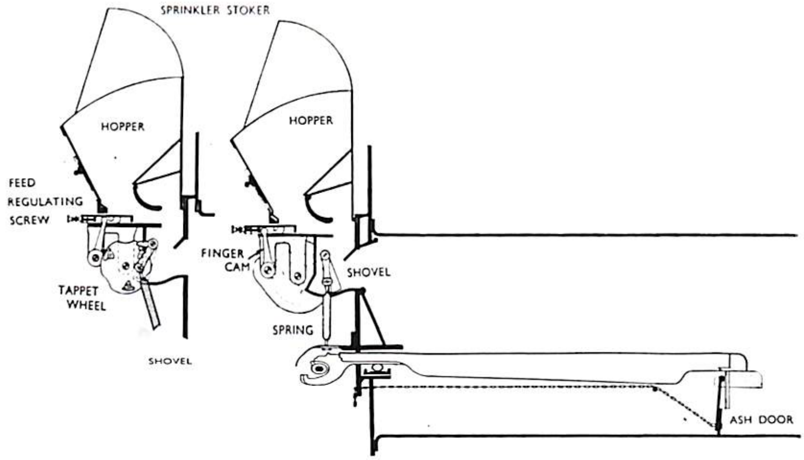



Fig. 70. The "Proctor" sprinkler stoker.

This is fed by a reciprocating ram, of which the length of traverse is adjustable and which determines the amount of coal fed each cycle. The ram finger is moved through a short shaft by a cog which engages a scroll incorporated in the tappet wheel. The shovel (fig. 71) is fixed to a loose shaft supported in self-lubricating bearings. A spring lever keyed to this shaft engages with a spring attached to a bracket on the stoker front. The tappet finger is raised against the tension of this spring by a tappet on a wheel keyed to the main driving shaft. This action swings back the shovel, and as this occurs a charge of coal is delivered by the ram and directed by a guide to the shovel. The tappet finger is released as the driving shaft revolves. The tension of the spring imparts a sharp forward movement to the shovel which projects the coal over the fire, and three tappets set at three different lengths of throw which overlap, produce a level spread over the length of the grate.

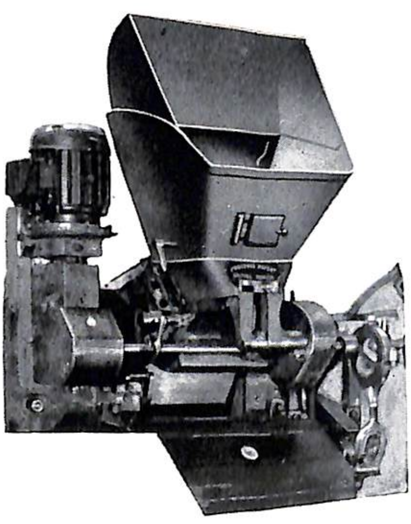


Fig. 71. The shovel for the Proctor sprinkler stoker, made in the form of a vee.

This splits the stream of coal and secures a more uniform distribution over the whole width of the furnace.

Fig. 72 (Left). A view of the "Proctor" sprinkler stoker showing the drive and the rack motion which regulates the speed of the bars.

$3\frac{1}{2}$ to $7\frac{1}{2}$ r.p.m. If no electricity is available a steam-driven countershaft at 100 r.p.m. or 200 r.p.m. may be fixed over the boiler and a belt drive arranged to gear with the above.

The gearbox has a dustproof cover, and the gears run in an oil bath. The bearings for the driving shaft, the ram finger shaft, and the moving bar camshaft in this instance are of the graphite self-lubricating type.

In the **"Triumph" Sprinkler Mechanism** illustrated in figs. 73–76, coal flows from a hopper to the front of a reciprocating ram, which delivers a pre-set quantity of coal in front of a spring-loaded swinging shovel which projects each charge in turn on to the fuel bed. The shovel is from 10–24 in. wide, depending upon the diameter of the boiler flue, and thus avoids the need to vary the angle of throw. Even distribution of coal along the grate is secured by the use of three adjustable nickel-chrome trips mounted in radial slots provided in the front plate of a tappet wheel.

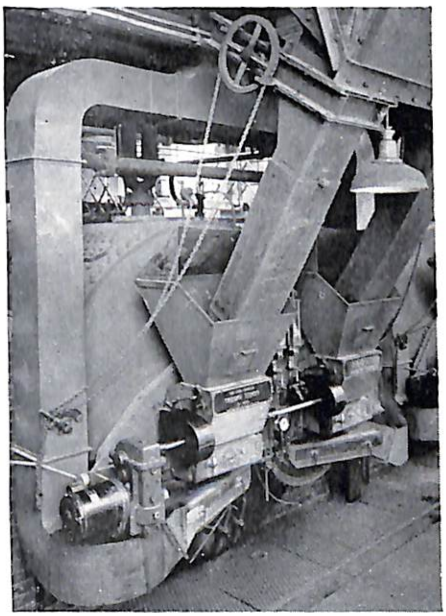
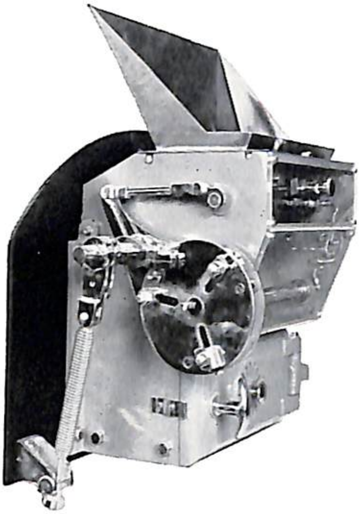


Fig. 73. The "Triumph" sprinkler stoker with stationary grate and fan-draught.

A deflector plate or coal feed gate is operated to cut off the flow of coal just before the shovel is released, and the angle at which the coal is delivered can be altered to suit different grades. The reciprocating motion of the ram is derived from a hardened steel scroll which engages with rollers suitably positioned in the tappet wheel. This is transmitted by a crank to the operating shaft in the ram chamber. The gearing is of the double reduction worm type. Lubrication is provided by a "Tecalemit" grouped nipple system, and by suitable oil reservoirs in the gear housing.



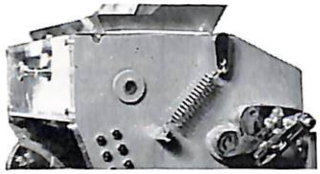


Fig. 75. A view of the "Triumph" sprinkler stoker from the side opposite that shown in fig. 74.

The shovel shaft extends through the box to operate the deflector plate in the manner indicated and synchronise the delivery of coal with the action of the shovel. Figs. 74 and 75 show how the three principal movements in the "Triumph" stoker are synchronised.

Fig. 74. The "Triumph" sprinkler stoker tappet plate.

This shows three adjustable tappets, and the spring lever with a tension spring attached to a bracket on the front of the boiler. The scroll which engages with rollers within the tappet is for the operation of the reciprocating coal feed. The adjustment of the ram or pusher is effected by a knob at the front.

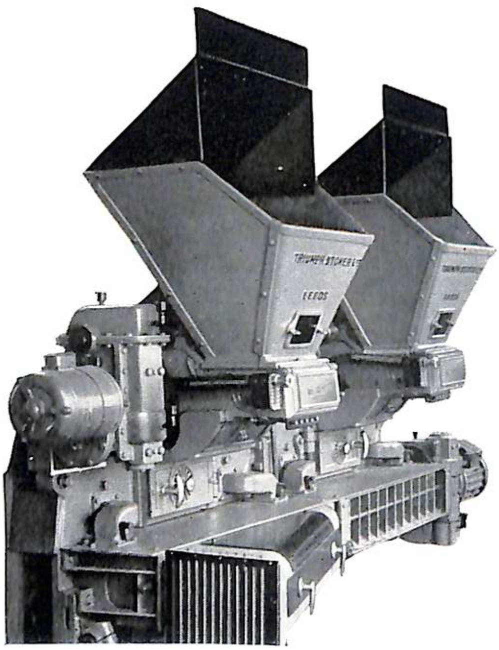


Fig. 76. A "Triumph" sprinkler stoker showing divided duct for fan-draught, distinct secondary supplies of air, drive and other details.

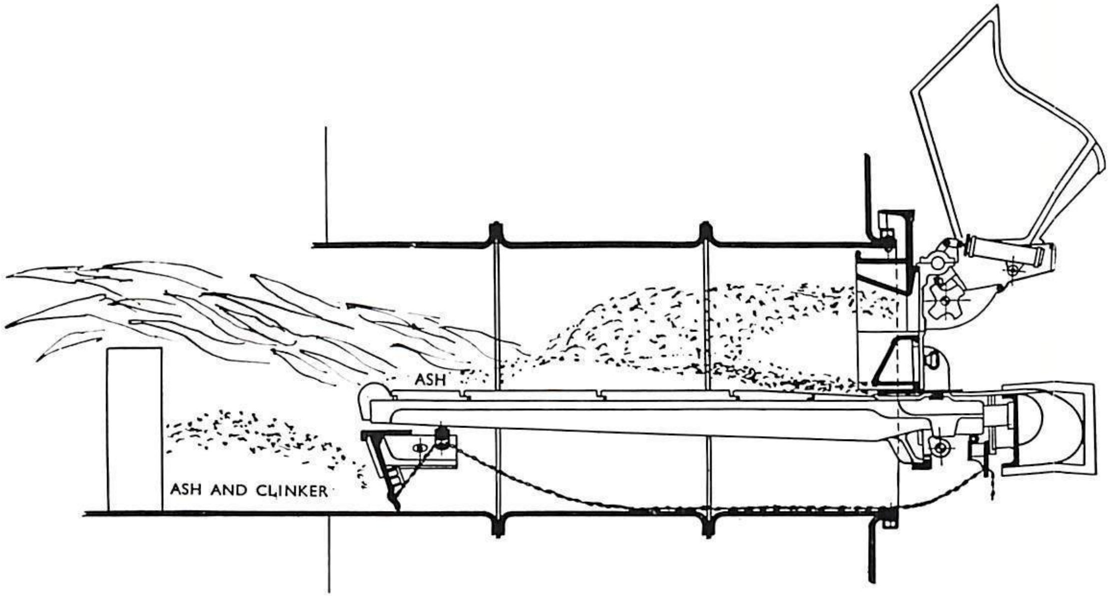



Fig. 77. The "Bennis" sprinkler stoker.

Coal is fed from a cast iron box at the base of the hopper by a pusher plate with an adjustable reciprocating motion, and falls on to a flat plate from which it is projected into the furnace at intervals by a swinging shovel of a shape designed to distribute the coal over the full width of the grate. A throwing cam (fig. 79) performs the function of the tappet wheel on the designs previously described. A trip lever or tripper on the steel rocking shaft to which the shovel is attached, is of hardened steel and is readily replaceable. The shovel is operated through the throwing cam, tripper and rocking shaft by a spring enclosed in a cylinder. This is first compressed by one of the fingers on the throwing cam, and when released it propels the shovel forward. The spring also presses on a piston within the cylinder, forming an air cushion which absorbs the shock when the spring is released; hence the term "pneumatic" gear (fig. 79). The rotating throwing cam or tappet which draws back the shovel has four different lifts, each of which sprinkles coal over 18 in. of a grate 6 ft. long. This method of distribution, which is common to all tappet or cam actuated shovels, allows a little time for the coal fed to each section to become incandescent between charges. The rate of feed may be varied from zero to 20 cwt. per hour and the capacity of the hopper is 3 cwt.

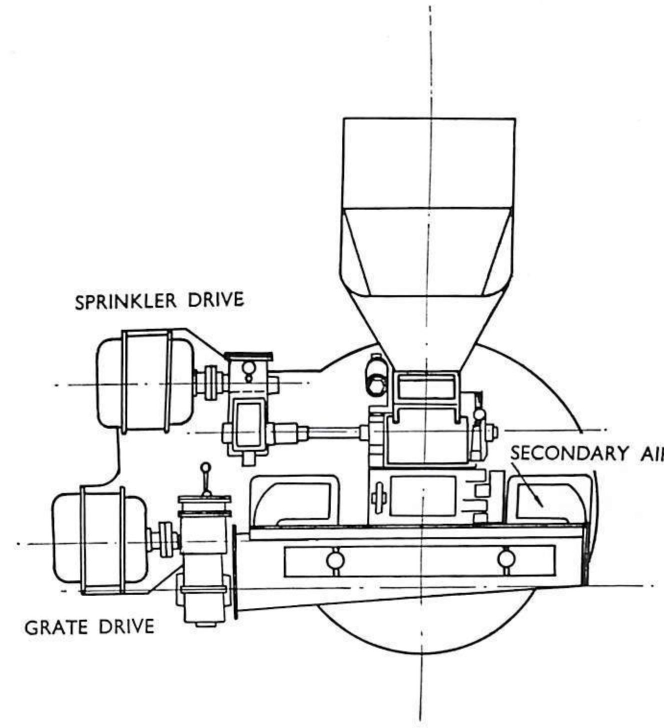



Fig. 78. A front view of the "Bennis" sprinkler stoker showing the three-speed motor and gear box which drives the sprinkler mechanism, and the three-speed motor and gear box which drives the self-cleaning grate.

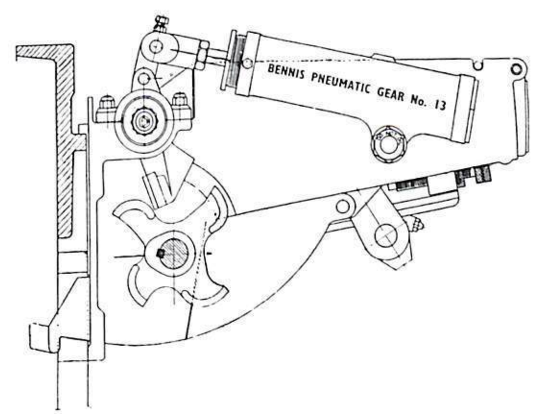



Fig. 79. The "Bennis" pneumatic gear; comprising throwing cam, trip arm and compressed spring within a cylinder with an air cushion to absorb shock.

Air is supplied through ducts from a forced draught fan mounted in a convenient position. A divided air box (fig. 51) provides an independent air passage to each trough bar, and ensures equal supplies of air to each part of the grate at a constant pressure. Overfire air may be taken from the air box and controlled by independent dampers.

**The "Bennis" Sprinkler Mechanism** is shown in figs. 77, 78 and 79 with a moving grate.

**The "Crosthwaite" Sprinkler Mechanism** (fig. 80) is of the swinging shovel type actuated by a cam with four fingers giving throws of four different lengths for a stationary grate, or by a cam with three fingers giving three throws of the same length on to the front of a moving grate, a development which invites comparisons of performance with semi-coking or with chain and travelling grate stokers and the same grades of coal.

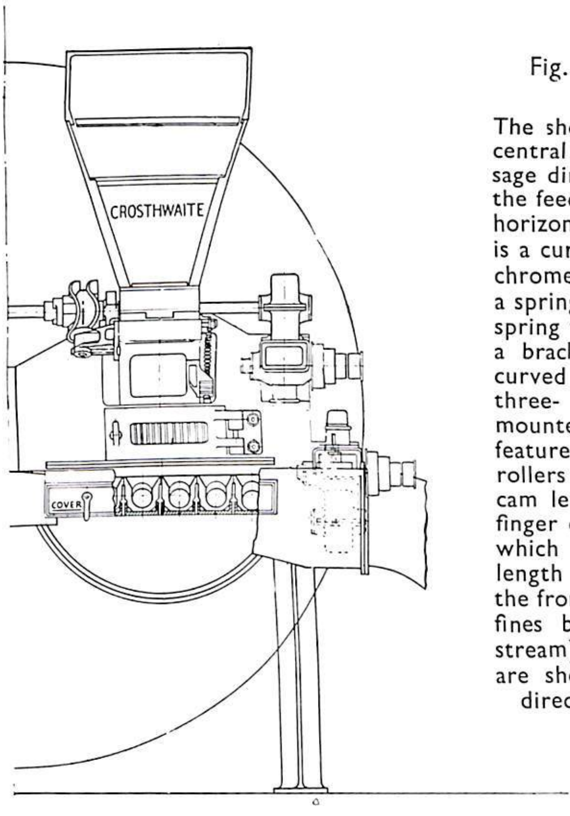



Fig. 80. The "Crosthwaite" sprinkler stoker.

The shovel is carried on a single central arm which swings in a passage directly through the centre of the feed-box. This is mounted on a horizontal shaft at one end of which is a curved cam lever with a nickel chrome steel roller, and at the other a spring lever attached to a tension spring which in turn is anchored to a bracket on the feed box. The curved cam lever is operated by a three- or four-point finger cam mounted on the driving shaft. A feature of this design is the use of rollers instead of dies on the curved cam lever, and the use of a three-finger cam with self-cleaning grates which gives three throws of equal length per revolution (simply on to the front of the grate, thus avoiding fines being thrown into the air-stream). Stepped cone belt drives are shown, but V belt, chain or direct gear can be substituted.

**The "Bennett" Sprinkler Mechanism** is also the spring-loaded shovel type and is shown in fig. 81.

**The hopper capacity** for all types of mechanical stoker is generally 2 cwt., and hoppers are usually provided with access doors and cut-off slides of one form or another. Firedoors are retained with sprinkler and coking stokers to allow hand-firing in an emergency.

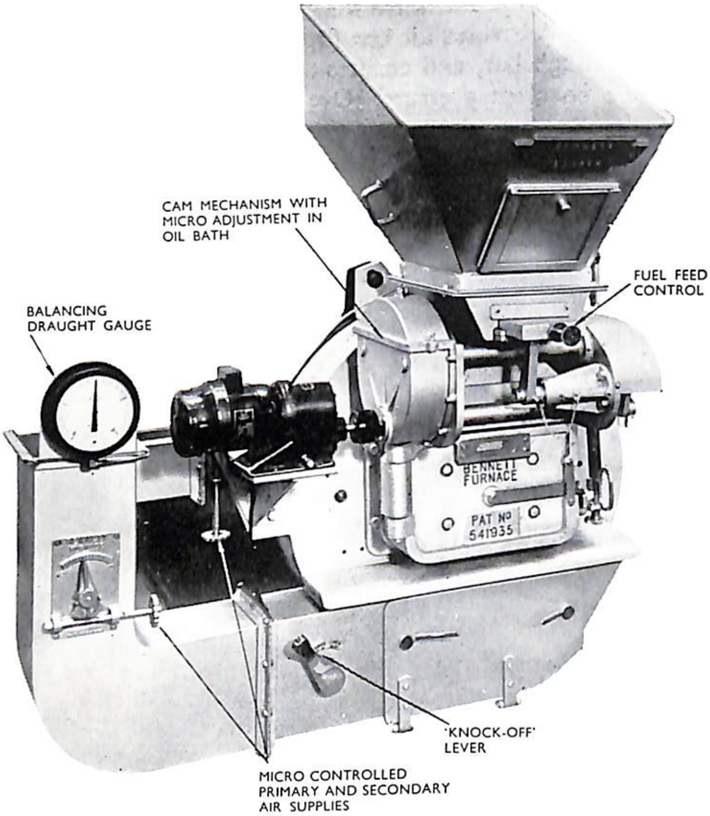



Fig. 81. The "Bennett" sprinkler stoker with a spring operated shovel and a semi-retort stationary grate with fan-forced draught.

The motor drive, slip coupling, gear box, tappet finger operating an adjustable feed mechanism, and the primary and secondary supplies of air should be noted. The air adjustments are shown. The air supply can be cut off quickly by the lever shown in the main air duct, but is not cut off automatically when the firedoor is opened. There are four adjustable throws per revolution of the tappet wheel.

## COALS FOR COKING AND SPRINKLER STOKERS

Sprinkler stokers may be defined here as a combination of sprinkler feed with a stationary or moving grate. They are designed to feed a wide range of coals from an upper limit of 2 in. to a lower limit of about 35 per cent through a $\frac{1}{8}$-in. mesh. The ideal coals are singles or 1-in. rough slacks with a slightly coking characteristic and a fairly high ash fusion temperature. Welsh coals with a volatile content of less than 10 per cent are being successfully fired by this means, but the boiler rating is reduced somewhat when these coals are used.

Grit carry-over with different grades of coal with shovel-type sprinklers and *moving* grates, operating under balanced draught, is indicated by the results of tests by Dunningham and Thornton, shown in Table XIV.

TABLE XIV

| | Per cent | | Steam average output lb./hr. | Burning rate lb./sq. ft. hour | Gross efficiency per cent. | Per cent heat loss to | | |
|---|---|---|---|---|---|---|---|---|
| | Dry ash | Through $\frac{1}{8}$-in. | | | | Fine gases | Grit | Carbon in ashes |
| Graded:— | | | | | | | | |
| Free burning .. | 6 | 2 | 13,938 | 37.4 | 78.3 | 14.0 | 0.7 | 0.4 |
| Medium caking | 4 | 4 | 14,241 | 36.2 | 77.7 | 14.6 | 1.0 | 0.9 |
| Strongly caking | 6 | 1 | 14,231 | 32.4 | 76.6 | 15.7 | 1.5 | 0.5 |
| Slacks:— | | | | | | | | |
| Free burning .. | 20 | 49 | 13,332 | 47.0 | 74.0 | 14.6 | 3.1 | 2.0 |
| Medium caking | 13 | 31 | 13,946 | — | 72.2 | 14.7 | 5.6 | 1.2 |

The gross efficiency was rather higher for free-burning than for caking coals, the maximum difference being less than 2 per cent.

Lower efficiencies are usually obtained with caking than with free-burning coals because lumps of coke produce a less uniform fuel bed. A bed 2–3 in. thick is most suitable for small-sized coal and small slacks, and 3–4 in. for larger-sized coal, such as nuts and 1-in. slacks. Broadly, the larger the size of the coal the thicker the fuel bed required for a given duty.

Grit carry-over increases with the percentage of fines, and also with the burning rate and output of the boiler, as indicated by the figures from tests by Dunningham and Thornton, shown in Table XV.

TABLE XV

| | Average load lb./hr. | Gross efficiency | Per cent heat in grit |
|---|---|---|---|
| Slacks | 10,000 | 72.3 | 5.0 |
| | 14,219 | 71.7 | 5.5 |
| | 11,741 | 74.0 | 3.4 |
| Graded | 16,340 | 77.1 | 1.4 |
| | 14,259 | 77.8 | 0.8 |
| | 11,932 | 78.0 | 0.9 |

Low ash coals usually perform better than high ash coals, because the fires require less attention and carbon loss in the ash is not as great. Coking and sprinkler stokers are *not* suitable for burning dry fines or washery slurries.

### A COMPARISON OF COKING AND SPRINKLER STOKERS

Sprinkler stokers are more flexible than coking stokers with top coking plates, both with respect to output and to the range of coals which can be efficiently burned. The efficiency of sprinkler stoking, however, falls off with increase in "fines" owing to the higher grit carry-over. Of coking coals, only medium coking coals with a relatively low fines content can be used with coking stokers.

Burning rates for both types do not generally exceed 30 lb. per sq. ft. per hour, the average being between 20 and 30. With graded coals and slacks the average is between 30 and 35 lb. per sq. ft. per hour.

The relative merits of coking and sprinkler stokers as generally agreed are summarised in Table XVI.

TABLE XVI

RELATIVE MERITS OF COKING AND SPRINKLER STOKERS

| | Coking stokers | Sprinkler stokers |
|---|---|---|
| Range of suitable coals. | Most efficient with medium caking coals of low ash and fines content. | Will burn free-burning and caking coals equally well, with a wide range in ash and fines content, but with an increasing grit loss and a lower efficiency as the percentage of fines increases. |
| Fuel bed. | Up to 12 in. in front. | Varies with the size of the coal. |
| Burning rate lb. per sq. ft. per hour. | Limited owing to the thickness of the bed. Not very flexible. Normal maximum about 35 lb./sq. ft./hour. | Very flexible up to about 45 lb./sq. ft./hour, with forced draught. |
| Distribution of coal. | Tends to be thin at the sides except when the coal is fed at grate level. | Uniform with rotary distribution, and reasonably uniform with spring-loaded shovels. |
| Draught. | More draught is required for a given output than with sprinkler stokers, owing to the thicker fire bed. | |
| Smoke. | Low. | Rather more than with coking stokers. |
| Grit carry-over. | Lower than with sprinkler stokers. | Increases with fines in coal and with burning rate. |

## OPERATING LIMITS

### The Effect of Air Supply.

*A free-burning coal* gives a compact bed with small air passages between the pieces. A coking coal swells into masses which have relatively large air spaces and fissures in them, so that air passes more easily through such a bed. A deeper bed is therefore required with coking coals for good combustion, and it is more difficult to maintain good average $CO_2$ contents in the waste gases with them, particularly at low burning rates.

*Swelling* tends to be greater with coking coals the smaller the coal, and it has been found that the maximum swelling occurs with all sizes when ignition is allowed to reach the grate. In addition to preventing ignition from reaching the grate, an increase in the primary supply of air causes a coking coal to behave more like a free-burning coal, producing in these circumstances a more uniform and compact fuel bed owing to the formation of smaller pieces of coke.

*Increase in ash content.* With free-burning coals an increase in ash content or in the rate of burning is accompanied by a reduction in swelling,

but with coking coals a reduction in swelling occurs only when the ash content and the rate of burning are both relatively high. On the other hand, high air rates tend to blow holes in the bed and are accompanied by an increase in grit emission.

*The cooling effect of air.* Free-burning, non-swelling, low rank coals form compact, uniform beds which break down evenly as combustion proceeds, and therefore transmit more heat to the grate than open irregular beds formed by high rank bituminous (swelling) coals. The cooling effect of air increases more quickly as the air rate is increased than the temperature of the bed. The temperature of the grate thus falls. The highest grate temperature should thus be obtained with the lowest burning rates. This is so with the free-burning coals, but with coking coals the highest grate temperatures are obtained at intermediate air rates. Increase in ash content reduces the grate temperature with free-burning coals at all rates, but with coking coals the ash content has no effect on the temperature of the grate at low burning rates.

*The effect of increasing the air rate with coking coals* is to weaken the structure of the bed and increase heat transfer from the fuel bed to the grate. This is greater with coking coals than the cooling effect of the increase in the quantity of air up to intermediate rates of flow. Coking coals should therefore be used to meet low or high loads and free-burning coals to meet medium loads, thus ensuring the most satisfactory operating conditions for grates.

*Good ignition is best assured* by reducing the primary supply of air to a minimum by a deadplate or similar means, and by the maintenance of a high furnace temperature. When ignition has been established, it is an advantage to use as high an air rate as possible in the middle zone to keep swelling at a minimum, as this produces a more uniform fuel bed. The supply of air should be least in the burning-off zone at the back of the grate, to keep excess air at a minimum.

**The Effect of Grading Coal.**

*Effect of fines.* The resistance of a fuel bed to the passage of air increases as the percentage of fines increases, until finally the air forms channels in the bed through which it passes. It has been found that this occurs with about 70 per cent of fines. The highest air rates are therefore possible with coarser grades.

*Effect of moisture.* The addition of water progressively lowers the resistance of a fuel bed to a minimum, after which there is a slight increase if more water is added. The resistance of a bed of coal or any other granular material, like sand, to the passage of air varies with the weight of dry material per cubic foot. The minimum resistance for industrial coals corresponds in all cases to the maximum water content which can be held by the material without drainage occurring.

*The combined effect of moisture and fines.* The resistance will obviously be affected by packing, and hence by the size range of the pieces and particles. With coals this is greater the greater the percentage of fines up to the limit

which gives the most compact bed. This is shown by the data in fig. 82, which gives the resistance of burning coal on a travelling grate at various distances along it with 5 per cent water added, and with complete wetting. With two exceptions the coals contained 70–80 per cent free moisture. The two exceptions had a low percentage of fines and required only 5 per cent of free moisture. The amount by which the resistance is lowered by moisture is greatest in the ignition zone.

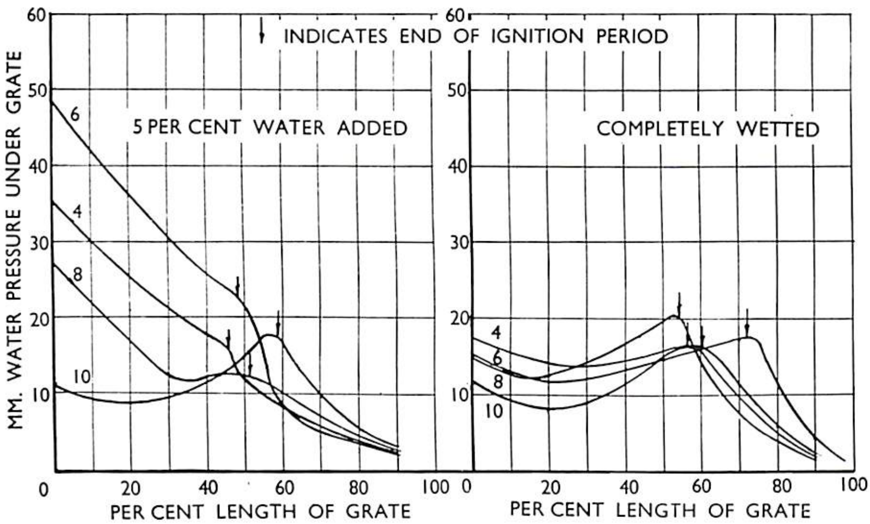



Fig. 82. Resistance of fuel bed along length of grate during combustion (after A. C. Dunningham).

## OPERATION OF COKING AND SPRINKLER STOKERS

After lighting a fire on the grate, firing is continued by hand with the grate stationary, and the fuel bed is broken up occasionally. A pressure of 15 lb. per sq. in. should be attained in not less than 8 or 9 hours. The natural or induced draught is regulated to maintain a steady fire during this period.

### Starting the Stoker.

*With moving grate and steam-jet forced draught.* Open the boiler damper fully and start the grate. Open the steam-jet valve by about a half turn. Start up the stoker at a low rate of feed, and as the steam pressure rises increase the rate at which coal is fed, gradually opening the steam-jet valve to three-quarters as the working pressure is approached.

*With moving grate and fan-forced draught.* Replace the air box covers which were removed to allow a natural or induced draught to flow through the grate. Close the dampers in the air ducts and on the forced draught fan inlet and start up the fan. Open these dampers slightly. Start up the grate and stoker, then gradually open the fire damper and increase the coal feed until the working pressure is obtained.

**Banking.**

Stop the forced draught fan and remove the air box covers. Close the steam-jet valve. Stop the stoker and grate mechanisms and allow the fire to burn down. Shut off the induced draught fan and position the boiler dampers to allow just sufficient natural draught over the grate to carry away the gases.

Push back the fire to expose about 12 in. of grate at the front. Hand-fire coal on to this, banking it up, particularly at the sides, to within 6 or 8 in. of the furnace crown, then close the dampers.

The grate must be kept stationary whilst the fire is banked and neither the steam jets nor the forced draught fan used.

**Starting from Banked Fires.**

Open the dampers. If during the banking period the steam pressure falls 30 lb. per sq. in. or more, at least one and a half hours should be taken in which to regain full pressure.

The same procedure is followed during this period, after breaking up the fires and removing ash and clinker, as when starting up from cold.

## MAINTENANCE OF COKING AND SPRINKLER STOKERS

It is doubtful whether any other mechanism has to work under conditions as severe as those under which mechanical stokers operate. They are subjected to heat from the fuel bed and wear from the coal. Efficient and regular cleaning is thus essential if they are to give continuous service, and all lubricated parts must be kept as free from coal dust as possible to prevent excessive wear.

Attention should be given to:—

(1) the grate;
(2) the stoker;
(3) the grate mechanism;
(4) the fans, steam-jets and ducting.

**The Grate.**

The air spaces between the bars must be kept clear from ash as an accumulation causes them to burn. The air ducts in trough bars should be cleared each time the fires are cleaned: and cleaning fires should be done whenever possible at low load, the stokers and moving grates being stopped in rotation. The fires are allowed to burn down somewhat before cleaning, and the dampers are partially closed during this operation to check the inrush of cold air into the furnace.

**Forced draught fans or steam-jets must be shut down before the fire is cleaned.**

**The Stoker.**

With shovel-type stokers, the timing of the feeding ram relative to the shovel must be checked periodically. If the ram operates too early, that is before the shovel has returned to its "cocked" position, coal will fall on top of the shovel and a certain amount will work over behind it. An accumulation of coal behind the shovel jams the machine.

The tappets, which actuate the shovel, wear. This reduces the tension in the spring and affects the distribution of the coal. They are therefore usually fitted with easily renewable tips of hardened steel. The spring should be checked for loss of strength due to fatigue, by observing the length of throw, and then tensioned when necessary.

**Stoker and Grate Mechanisms.**

All wearing parts should be kept free from coal dust, which is also liable to penetrate into bearings which have worn slack.

The oil level in the gearboxes should be maintained and the oil changed every eight weeks. All nipples should be greased every four hours and oil lubricators filled up at the same interval.

The shaft across the furnace front, which carries the driving cams for the bars of a moving grate, should be kept lubricated with black axle grease. This reduces the wear on the cams to a minimum and ensures that the bars travel their full distance into the furnace.

Electric motors require little attention other than the lubrication of the bearings about once every six months.

**Plant Down for Inspection.**

When the boiler is down for inspection the coal hopper should be disconnected, cleaned and overhauled.

Driving shafts, bearings, brackets, driving belts, and the gearing of the stoker, prime mover and fans should be cleaned. Bearings are washed in paraffin and packed with high melting point grease. Grease boxes should be cleaned and the pipes tested for free passage with a stout piece of wire. Gearboxes should be drained and flushed out with paraffin or a suitable detergent before refilling. If a gearbox is dismantled, care must be taken to mark the gears before they are removed so that they mesh correctly when replaced. In one stoker gearbox there are 90 ways in which the gears will mesh, only six of these being correct.

Moving bars should be cleaned with wire brushes and given two coats of brown oxide of iron and boiled oil.

The steel and iron parts, including the frame and bearers, should be thoroughly cleaned and painted with a good mineral black mixed with linseed oil and a little kerosene oil before the stoker is replaced. By thorough cleaning is meant the brushing away of all loose dirt, followed by action with steel scrapers and wire brushes.

# CHAPTER VII

# CHAIN AND TRAVELLING GRATE STOKERS

## COMBUSTION ON A CHAIN OR TRAVELLING GRATE

A bed of burning coal on a chain or travelling grate, with an adequate supply of air, may be divided into three zones:—

(1) the front, on which ignition occurs and travels downwards to the grate;

(2) the middle, where combustion of both volatiles and fixed carbon occurs;

(3) the back, where the residual carbon is burned off from the ash and clinker.

This is shown diagrammatically in fig. 83.

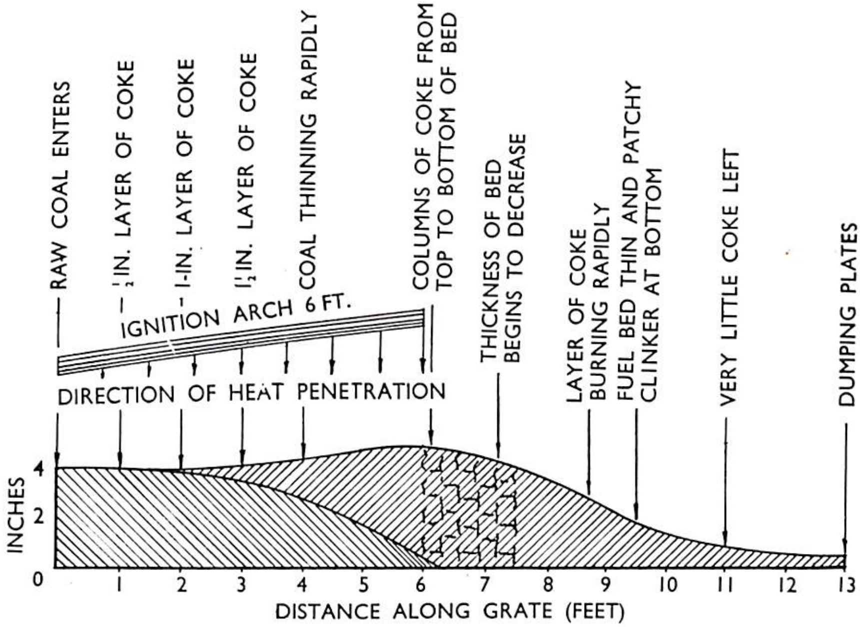



Fig. 83. Combustion on a travelling grate (after E. Grumell and his collaborators).

The gases given off at the front are water vapour, hydrogen, hydrocarbons and tarry vapours, carbon monoxide and carbon dioxide. The middle zone produces a relatively high proportion of carbon monoxide to

carbon dioxide at the beginning, and ends with the absence of monoxide. Free oxygen appears at the back in the final burning-off stage, during which the proportion of carbon dioxide steadily falls.

**Every combustible mixture of gases has its own characteristic flame speed or rate of burning.** This varies with each combustible gas or mixture of combustible gases and with the amount of air present. All solid fuels are gasified before they burn, thus carbon first combines with oxygen to form carbon monoxide, which then burns to carbon dioxide. The rate at which a given coal will burn upon a grate thus depends upon its constitution and upon the supply of air. The greater the rate at which air is supplied, up to a characteristic maximum for each mixture, the greater the possible rate of burning.

**The rate at which air can pass into a bed of coal** depends upon the design of grate, the difference in pressure below and above the fuel bed, the size of the coal, the free moisture present, and the depth of the bed. If the size and depth of coal remain the same, the relative lengths of the three zones of a travelling grate at a given speed with a uniform distribution of air under the grate will thus vary with the flow of air through the bed; that is, with the air rate. And conversely, the relative lengths of the three zones may be varied by changing the distribution of air to different parts of the grate.

In theory it should be possible to vary the speed of the chain and the coal consumed per square foot per hour from zero to a maximum, dependent upon the design and application of the grate, but in practice the operating limits are set by the need to ensure complete combustion (minimum unburned carbon in the ash) on the one hand, and to avoid overheating the grate on the other.

## OPERATING LIMITS

Grate temperature is the resultant of two factors, the heating effect of the burning fuel and the cooling effect of the air passing through it. Grate bars in contact with fresh coal are not heated until ignition reaches the grate. There can therefore be no rise in temperature of the links of a chain or travelling grate until ignition reaches them. The temperature then rises to a maximum and falls steadily to the dumping plate. The speed of the chain may therefore be set sufficiently high to prevent ignition reaching the links before the end of the grate is reached, but the loss of combustibles unburned could be very great under these conditions. On the other hand, increasing the air rate causes a greater proportion of the coal to be burned off before ignition reaches the grate, and thus protects the links from damage due to high temperatures with a layer of ash. This heating effect will obviously be greater at all burning rates the lower the percentage of ash. There is, therefore, with any coal, an ash content which will adequately protect a chain or travelling grate against damage due to overheating. This varies normally from 12–16 per cent.

The rate at which coal must be burned upon a grate is, however, governed by the demand for steam. It is not, therefore, always possible to effect the

heat release required at all loads and at the same time operate under most favourable grate conditions. There is also a difference in the behaviour between different grades of coal with changes in air rate.

## CHAIN AND TRAVELLING GRATES

The moving bar grates already described carry burning coal through the furnace, ash and clinker being discharged from the end of the bars. This type of grate was invented in 1822 and has since been in continuous use. An alternative means of achieving the same result is to use a grate, the links of which form an endless chain which serves also to carry the burning coal through the furnace to the ash dumping point, the chain returning to the front underneath the section which forms the grate, to repeat the process. The chain grate stoker was invented by Juckes in 1841. The original patent specification is remarkable in that it sets out the salient features of this machine as we know it today. The moving bar grate of the coking stoker similarly has changed but little since 1822.

Chain grate stokers consist of an endless chain of short cast-iron grate bars, linked together and driven by sprocket wheels mounted on a shaft at the front of the boiler (fig. 84). The section forming the grate is supported by skids or rollers, and sometimes by skids on the top or forward rim, with rollers on the bottom or return rim. A hopper is provided to supply coal to the grate, and this has an adjustable outlet gate or guillotine door, with which to vary the thickness of the coal on the grate. An arch of firebrick is built over the front part of the grate which, heated to incandescence by radiation from the bed, assists the ignition of incoming coal. The speed of the chain is adjusted through a gearbox.

The travelling grate differs from the chain grate in that grids or insets of cast-iron are mounted on carrier bars to form the grate, and are driven by an endless steel chain.

### Limitation Imposed by Shell Boilers on Grate Areas.

The fundamental limitations in design of shell boilers arise from the need to arrange the furnace with its fire grate, together with adequate heating surface and "steam space," within a cylindrical shell. In a Lancashire boiler, the diameter of the furnace tubes is limited by this to about one-quarter of the diameter of a small boiler and to about one-third of the diameter of a large boiler.

The practice has consequently developed of using good quality or graded coals with shell boilers in order to obtain the highest possible heat release from this restricted grate area, and by this the highest possible steam output. There is no limit, however, to the size of grate which can be used with water-tube boilers, as the grate may be given the area necessary to obtain the maximum possible boiler output with any grade or type of fuel.

The chain grate stoker made little progress until the water-tube boiler was introduced, as it did not fit into the limited furnace space of shell boilers so well as moving bars. Chain grate areas up to nearly 900 sq. ft. are used with water-tube boilers, on which "almost any fuel from anthracite duff to wood waste and peanut shells" is burned. In short, the chain grate has been

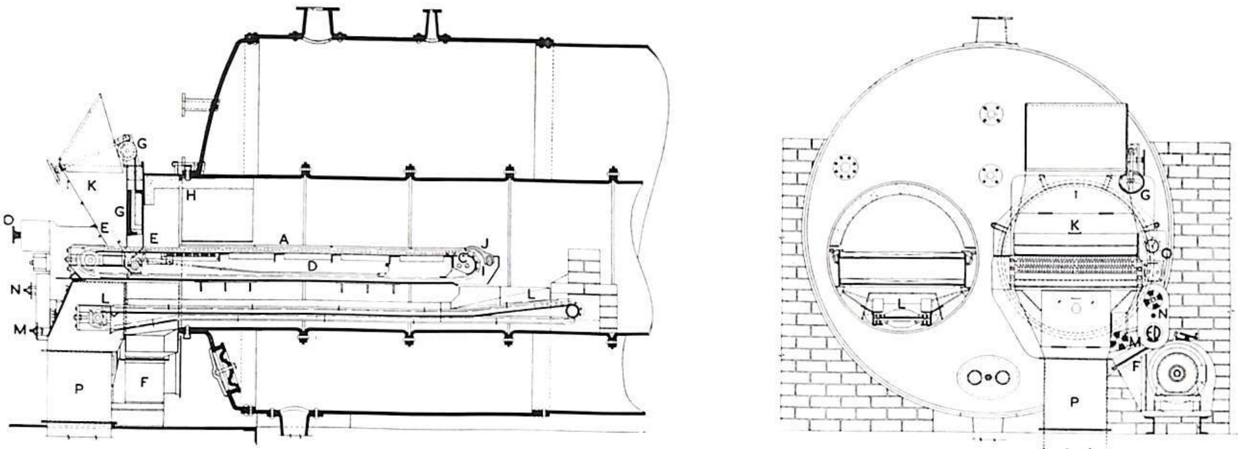



Fig. 84. The Danks "Oldbury" chain grate stoker.

A. The grate is an endless chain of cast iron links.
B. The common links and driving links are connected together by steel rods and driven by sprockets mounted on a high tensile steel shaft at the front. The shaft is supported by lubricated journal bearings with adjustable blocks by which tension may be adjusted.
C. A curved skid extends the full width of the chain and ensures even distribution of its weight. No lubrication is required.
D. Air box. Doors are provided along each side to facilitate inspection and repair.
E. Air is admitted at each side at the front and is separately controlled to front and rear compartments.
F. Fan draught. Each stoker has its own unit.
G. Adjustable firedoor with a refractory lining to regulate depth of coal on the grate. This is sealed with ash when banking, and operated by worm and wheel. The height of the door from the grate is indicated on a circular scale.
H. Ignition arch of refractory.
I. Fine ash falls out from between the links and the grate is cleared by the scissor-like action between the links as they travel round each end of the grate.
J. Ash or dumping plates check discharge of ash and keep the end of the grate covered.
K. The hopper extends the full width of the grate. Hinged flaps at the bottom of the hopper fronts open inwards and allow a slice to be used for the removal of clinker from the side walls without disturbing the fire on the grate.
L. Ash conveyor.
M. Indicator: speed of ash conveyor.
N. Indicator: grate speed.
O. Grate speed regulator.
P. Ash chute.

proved to be pre-eminently suitable for the burning of poorer coals under water-tube boilers, and was developed principally to burn medium quality coals at rates from 15–30 lb. per sq. ft. of grate per hour, with natural or induced draught. It is best suited for free-burning, high volatile coals with a fairly high ash content, say, 12-16 per cent as fired. The coal should also pass through a 1-in. mesh and contain a sufficient percentage of fines to form a compact bed.

A study of the burning of coal on chain and travelling grates by E. S. Grumell and his collaborators has shown that combustion occurs broadly as indicated in fig. 83. Carbonisation of the coal proceeds from the surface downwards. A layer of coke thus forms at the surface and becomes progressively thicker until carbonisation extends the full thickness of the bed. With natural or induced draught this occurs about 6 ft. from the front of the grate.

**Chain and Travelling Grates for Shell Boilers.**

The quality of coal supplied to British industry has undergone a great change since the end of the Second World War. The supply of graded coals is more limited, and extended mechanisation in mines has increased both fines and ash. Coals containing high proportions of fines or ash are therefore having to be used in increasing quantities with shell boilers. This has imposed changes in design of mechanical stokers and grates, especially in the application of fan-forced draught, in an endeavour to obtain the maximum continuous ratings from shell boilers with poorer quality coals. Hence, as chain and travelling grates have come to be regarded as machines for burning coals with relatively high ash and fines contents, it is not surprising that these stokers are being developed for use with shell boilers, fan-forced draught being used to make a shorter grate equally effective for complete burning off. The step has also been taken, presumably on the grounds of necessity with a continuously moving grate, and of proved reliability in other applications, of increasing the nominal grate length with Lancashire boilers from 6 ft. to 8 ft. to allow a longer burning-off zone and to give greater flexibility in grate speeds.

**Chain or Travelling Grates compared with Moving Bar Grates.**

The moving bar grate was originally designed as a part of the coking stoker, but is also used nowadays with forced draught for shovel-type sprinklers with, for example, three throws, the longest of which falls short of the back of the grate by a distance sufficient to allow complete burning off before ash is dumped (fig. 77). In one design the throws are all to the front of the grate. The same result is obtained when coal is thrust on to the front of a moving grate in a steady stream. The difference between these practices and a true coking stoker is the absence of the heap of coal on a coking plate at the front of the grate, and the use of fan draught with trough bars to effect a more uniform distribution of air. Chain or travelling grate stokers also feed coal in a steady predetermined stream to the front of the grate, no dead plate is fitted, and the distribution of fan-forced draught is effected by an air box through which supplies to the front, centre and rear

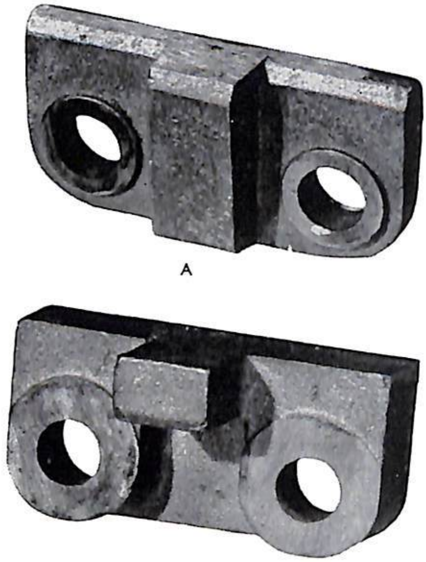



Fig. 85. Common link A, and driving link B, for the "Danks" chain grate stoker.

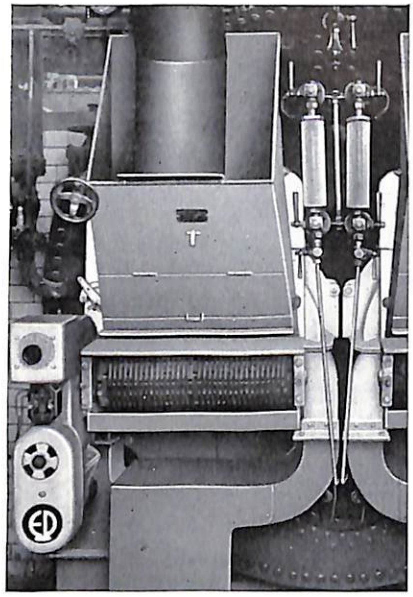


Fig. 86. A front view of a "Danks" chain grate stoker on a Lancashire boiler.

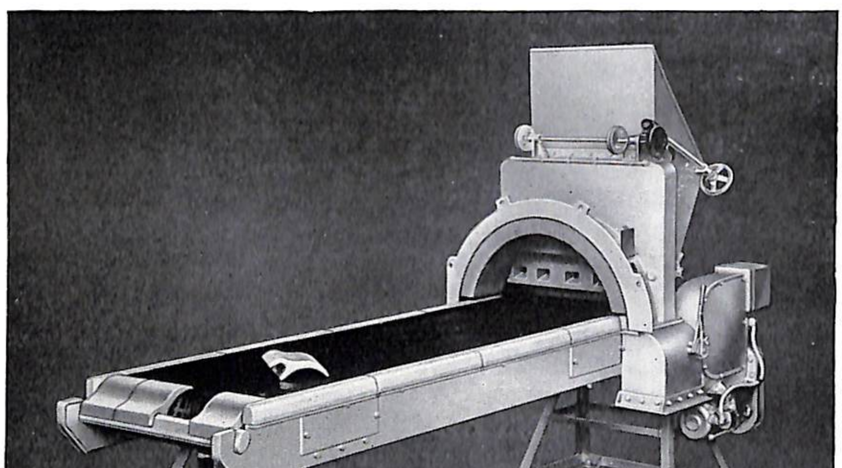


Fig. 87. A rear view of the "Danks" chain grate stoker withdrawn from a flue on to a specially made trolley for inspection and/or repairs.

are controlled. This permits the use of a longer grate, as the rear section may be used simply as a burning-off zone with a controlled air supply.

The thickness of fuel bed required is the same for the same coal and the same duty with each of these machines, with the same length of grate, but the bed is not disturbed to the same extent by a chain or travelling grate as by moving bars, so that provided the air pressure under the grate is the same, "carry-over" with the same grade of coal may be expected to be somewhat less; or, alternatively, coal with a higher proportion of fines may be burned. With shorter self-cleaning grates a thicker fuel bed is required, to compensate this factor and/or a lower maximum grate speed. The advantage gained by installing chain or travelling grates, therefore, lies principally in the wider range of coals with high ash and fines contents which can be used economically by their aid.

## CHAIN GRATE STOKERS

**Construction.**

*The grate surface* is built up and maintained from an endless chain of cast-iron links. The upper strand of the chain is supported partly on a flat steel plate which forms the air box and partly on skid bars. The lower strand of the chain is supported on a flat plate which forms the bottom of the air box.

*The links* are die cast from special grades of cast-iron, and have a minimum of heat absorbing surface and a maximum of heat dissipating surface within the limits of each design. Air spacing is regular and very fine so that riddlings are low.

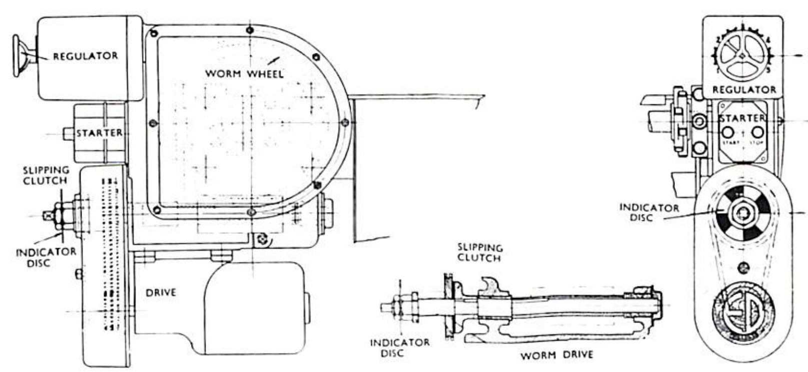



Fig. 88. The direct chain drive and regulator for the "Danks" chain grate stoker.

Note the disc which enables the operator to see at a glance whether the stoker is working or not, and the square ended shaft which may be used to operate the grate by hand.

*The drive.* The "Oldbury" chain grate stoker is driven by a totally enclosed, geared variable speed D.C. motor through a chain drive to a machine-cut worm and wheel, the latter being mounted on the end of the driving shaft (fig. 88). The speed of the motor is controlled by a regulator

which is built into the casing of the main gear. This provides any desired grate speed up to a fixed maximum. A rectifier is installed when the supply is A.C. An interlocking device ensures that the motor is always started up at the lowest speed. The gears are enclosed in an aluminium casing and both the worm and chain drives run in oil. A safety clutch protects the gears and the motor from overload. The grate can be operated by hand in the event of a temporary failure of power.

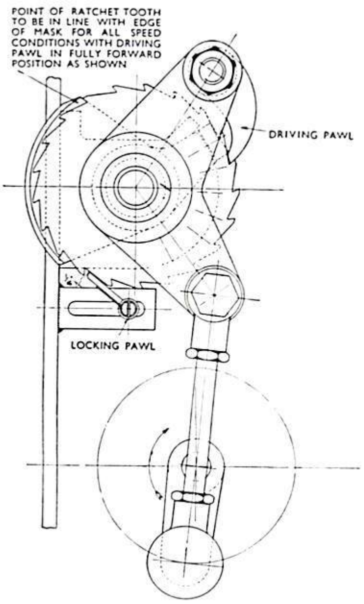



Fig. 89. A ratchet or intermittent drive for the "Oldbury" stoker. This is included as it shows clearly the function of the mask or selector plate and the position in which it must be set for accurate working.

In the "Bennis" chain grate stoker, speed variation is obtained from a totally enclosed motor-geared unit suitable for working from an initial supply of alternating current. The final speed reduction is by chain drive and worm gearing, running in an oil bath and totally enclosed in an iron-clad dust and oilproof case. The speed of the grate is controlled by a drum-type controller. A "stop" and "start" push-button contactor starter is included, fitted with overload and no-volt protection devices. The motor can be started or stopped at any particular speed.

*The frame* is normally a steel unit of all-welded construction which also forms an air box.

*A secondary supply of air* may be provided through the refractory lining of the fire door from the main supply, but it is claimed that sufficient air normally passes through the thinning fire bed at the rear with chain grates to burn the volatiles, so that a secondary supply of air is seldom required.

*The hopper.* If coals containing a large percentage of fines are to be burned with a minimum of grit carry-over, the fuel must be laid evenly on the grate; hoppers therefore extend the full width of the grate.

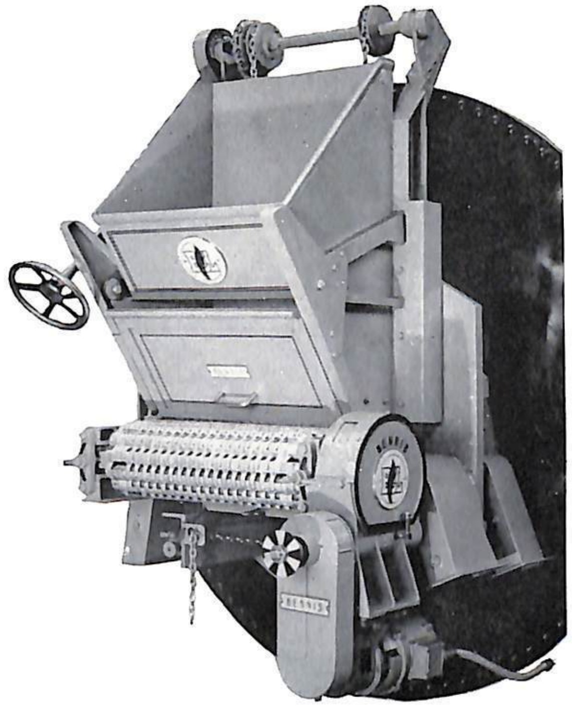


Fig. 90. A front view of the "Bennis" chain grate stoker.

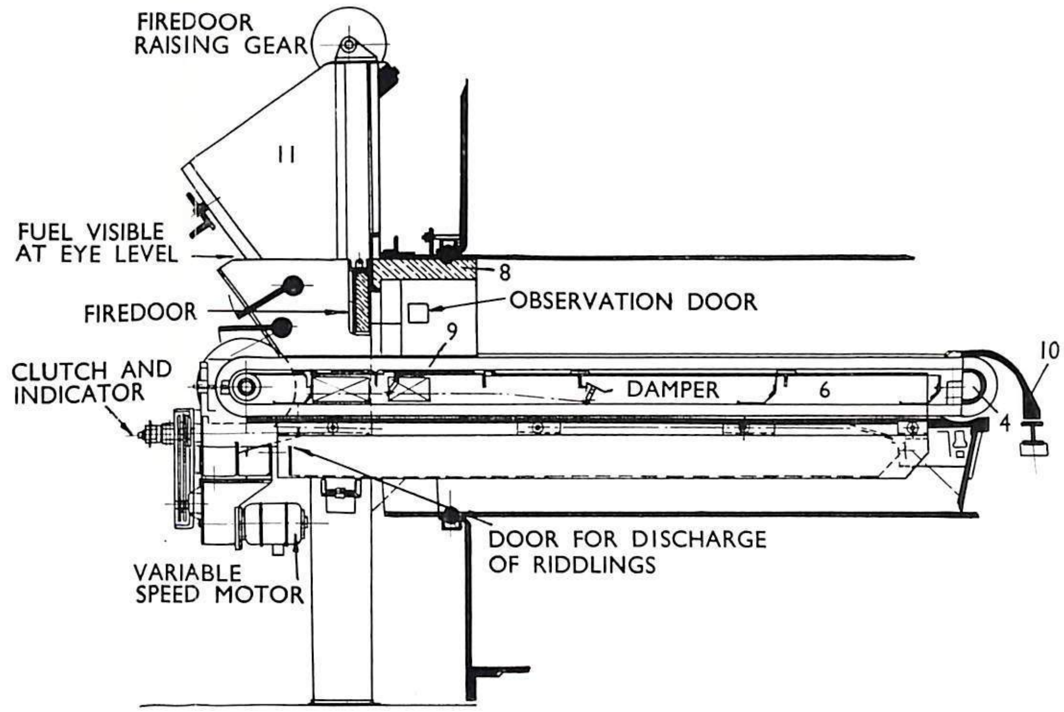



Fig. 91. A cross-section of the "Bennis" chain grate stoker.

1. The grate is an endless chain of cast iron links.

2. Links are mounted on bright round steel bars with washers and heat resisting locking nuts on the ends: the locking nuts are completely shielded from furnace heat and gases by the specially designed side sealing links.

3. The chain is driven by sprockets fitted to a steel shaft which is supported in self-lubricating journal bearings with adjustable sliding blocks by which chain tension is adjusted.

4. A carrier plate.

5. The machine is fitted with rollers to facilitate its removal for inspection.

6. The grate is divided into separate cells or compartments. Air at a comparatively low velocity enters the front cell and a proportion of this air, dependent on the nature of the fuel to be burned, is allowed to pass through to the second cell. The quantity can be determined by the position of the damper separating these two cells. Accurate adjustment of the damper is obtained by the use of remote control gear situated at the front of the machine.

7. Fan-draught is supplied through ducting with separate controls for each unit: remote control is effected from the front of the stoker.

8. The ignition arch is of plastic refractory, jointless and spall-resisting.

9. A deadplate to control ignition of fuel is at the front end of the grate.

10. Ash or dumping plates are fitted for certain fuels to check the discharge of ash.

11. The hopper extends the full width of the grate and is in two parts, so arranged that the operator can readily observe that coal is available. The lower half of the hopper front can be removed and the firedoor raised to a sufficient height to allow coal to be hand-fired in emergency.

Fig. 92. Front and back views of the three types of links for the "Bennis" chain grate.

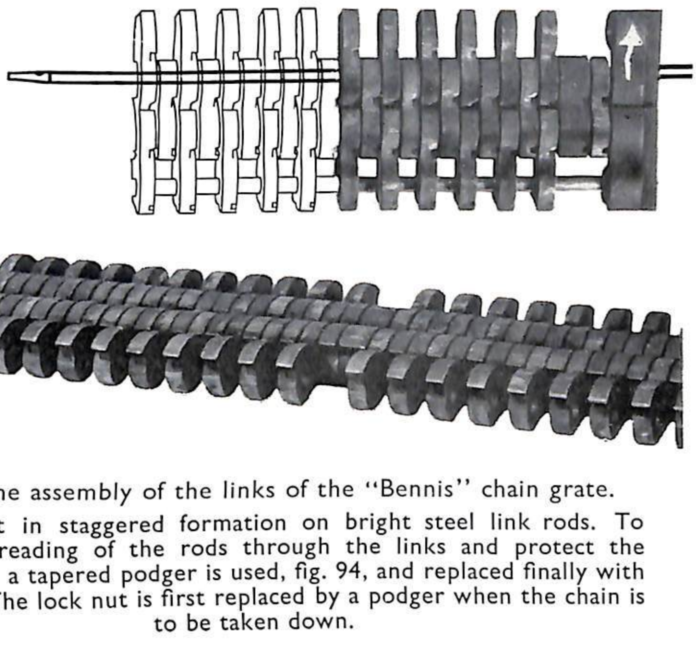


Fig. 93. The assembly of the links of the "Bennis" chain grate.

They are set in staggered formation on bright steel link rods. To assist the threading of the rods through the links and protect the screwed ends a tapered podger is used, fig. 94, and replaced finally with a lock nut. The lock nut is first replaced by a podger when the chain is to be taken down.

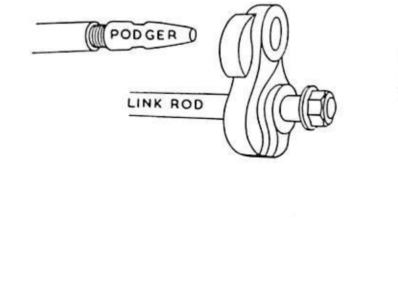



Fig. 94. The use of a podger when assembling or taking down the "Bennis" chain grate.

*Ash extraction.* The "Oldbury" stoker can be fitted with an ash extractor, which consists essentially of a self-contained scraper conveyor, driven from the stoker drive (fig. 84). This lies in the bottom of the flue beneath the stoker. The ash is continuously brought to the front of the boiler by it, and discharged into a water-sealed ash conveyor, which in turn discharges into an ash bunker outside the boiler-house. The extractor eliminates the opening of ash doors which is necessary with hand extraction, and is water sealed to prevent the ingress of cold air. It is claimed that the capital cost of the extractors and associated conveyor can be justified where the boiler plant consists of, say, five or more boilers.

**The Danks "Oldbury" chain grate stoker** is shown in detail in figs. 84–89, and the **"Bennis" chain grate stoker** in figs. 90–94.

**Maintenance of the "Oldbury" Stoker.**

*The chain.* Tension should be not more than is required to drive the chain without the links bunching up at the front. If the tension is more than this the load is increased on both links and driving gear, and excessive wear may result.

*Driving gear.* A continuous drive is effected by a variable speed D.C. motor. Details of the drive and regulator are shown in fig. 88. This is connected with a worm shaft by a chain which runs in an oil bath. Slackness in the chain is taken up by adjusting the shims under the feet of the motor. The brush gear and controller contacts should be examined periodically, say monthly, and cleaned when the stoker is not in use. When the current is A.C. and a rectifier has to be installed, this unit should also be examined monthly and any dust removed.

*The safety clutch.* The drive is protected by a friction clutch which is held tight by a spring at the front end of the worm shaft. The tension on the spring should be such that the grate can just be driven and stopped easily with the aid of a handle applied to the square end of the worm shaft (see fig. 88). Should the grate stop, it is wound back slightly by hand and restarted. This will clear a slight obstruction, but if a start cannot be made after one or two attempts, the cause of the stoppage must be found and removed. The spring of the safety clutch has to be eased before the grate can be turned by hand. **On no account should force be used to clear an obstruction, as this will almost inevitably break the grate.**

*Lubrication.* Points for lubrication are provided and should be tended once per shift. The oil recommended for use in the motor gearbox, worm gear and chain is Castrol XXL, Mobiloil D, or equivalent.

*Ash handling.* When ash is removed by hand the forced draught or chimney draught should be reduced, care being taken to restore them when the operation has been completed.

*Overhaul.* Detailed instructions are provided by the makers for the renewal of damaged links, and for the withdrawal of the stoker from the flue for overhaul and replacements.

## TRAVELLING GRATE STOKERS

**The "Thompson" Travelling Grate Stoker.**

The "Thompson" travelling grate stoker is illustrated in figs. 95–102.

The advantages claimed for the Thompson travelling grate compared with a chain grate are:—

(1) the drive is not effected through the grate, so that allowances for expansion of the grate surface can be more easily made;

(2) individual grids may be replaced without disturbing the drive;

(3) fine ash and riddlings are more easily discharged from the underside.

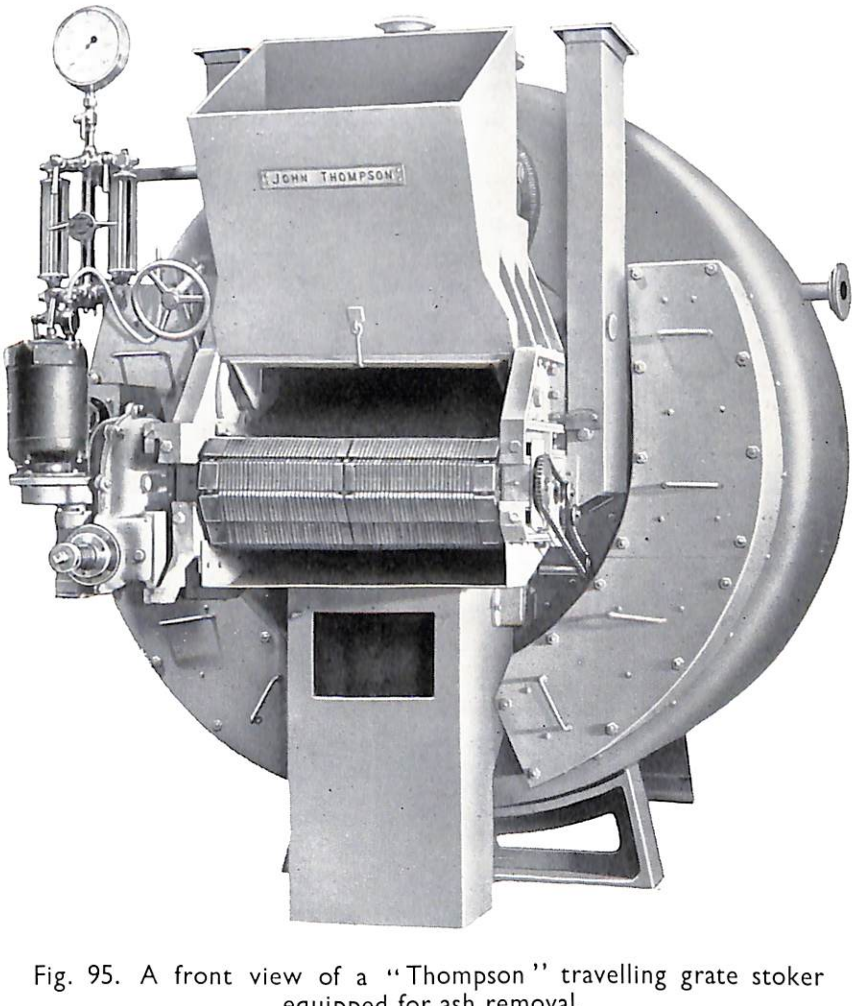



Fig. 95. A front view of a "Thompson" travelling grate stoker equipped for ash removal.

On the return run the grids pass through the wind box, where they are cooled, and pick up fine ash which is discharged as the grids "take the turn" at the front.

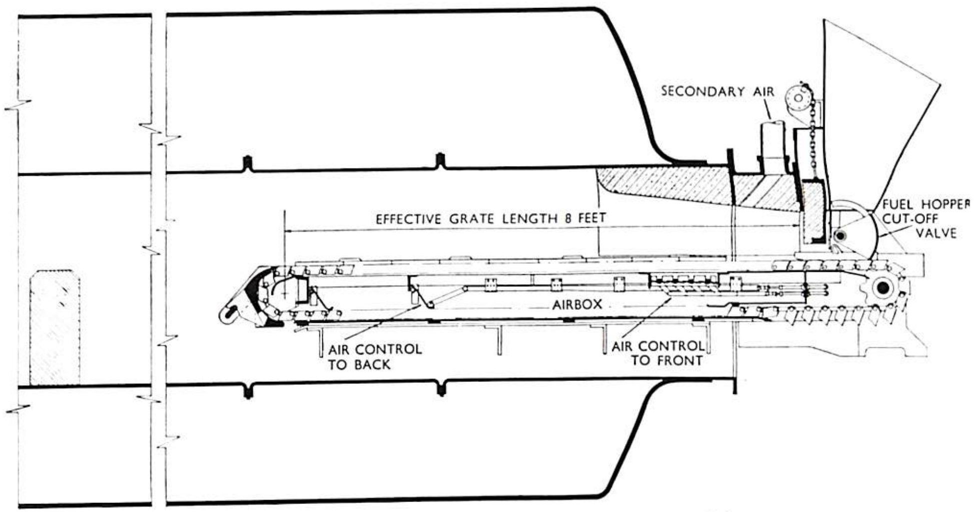
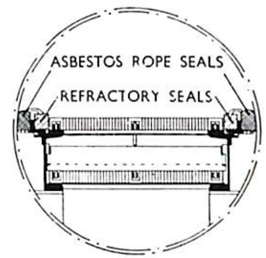



Fig. 96. A cross sectional elevation of the "Thompson" travelling grate stoker.

Fig. 97. The grate is sealed along each side to prevent ingress of excess air.




1. The grate is built up of cast iron common, centre and outside grids. A hole is machined in the grids, which are then mounted on a tube which is placed on a steel rod stretching between adjacent chains. They provide an even surface on the top side of the grate, and are free to hang down as they are carried along on the underside.
2. Fine ash and riddlings are picked up as the grids pass through the windbox and are discharged as the grids take the turn at the front.
3. The drive is by variable speed motor through reduction gears mounted on the stoker side frame. As the drive is not effected through the grate, individual grids may be replaced without disturbing the drive.
4. Adjustment of the grate surface and tension in the chain are effected by adjustable front bearing blocks.
5. The primary supply of air may be by forced draught fan through ducting with a secondary supply taken from it, or by a separate forced draught fan for each unit.
6. The hopper is fitted with a coal cut-off valve.
7. The firedoor is operated by a wheel and screw to adjust the thickness of the fuel bed. An indicator shows the depth of the coal on the grate.
8. The grate surface and the main frame may be withdrawn for inspection leaving the hopper and ignition arch in place. The ash conveyor (when fitted) may be withdrawn as a separate unit.

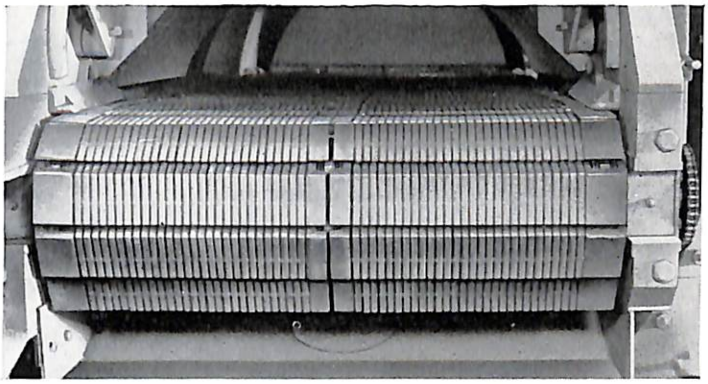


Fig. 98. A view taken from the front of a "Thompson" travelling grate stoker, showing the grate surface.

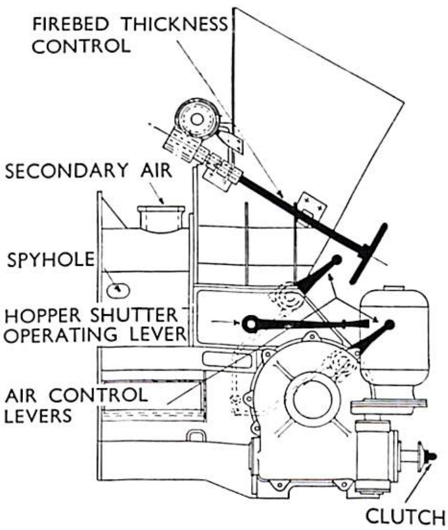



Fig. 99. A side view of the "Thompson" travelling grate, showing the controls for the guillotine door, the hopper shutter and air supplies.

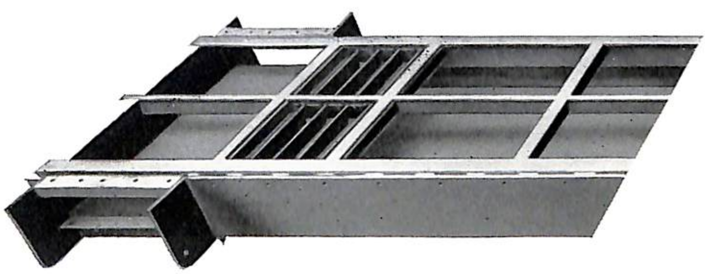
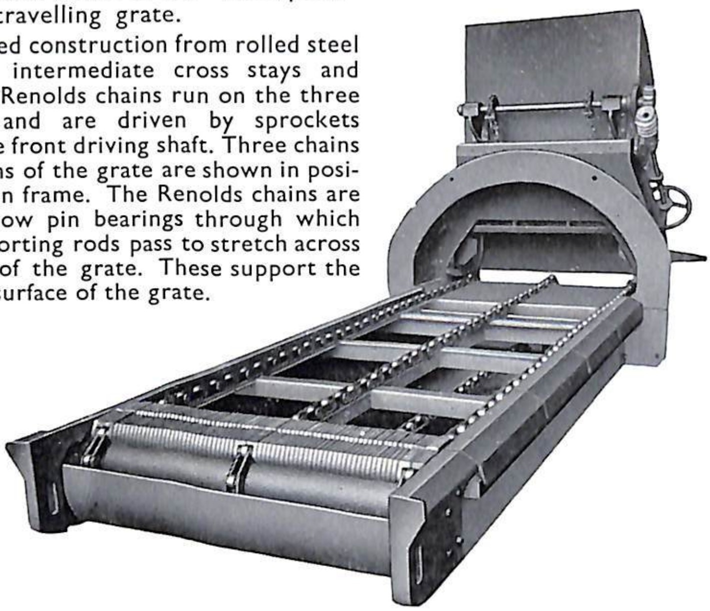


Fig. 100. The air box of the "Thompson" travelling grate.

Air is admitted into the air box at each side and air vanes are provided to control the supply to the front and back of the grate at various loads. A secondary supply is taken over the fire and discharged through the ignition arch to burn volatiles.

Fig. 101. The main frame of the "Thompson" travelling grate.

It is of all welded construction from rolled steel channels with intermediate cross stays and bottom plate. Renolds chains run on the three tracks shown and are driven by sprockets mounted on the front driving shaft. Three chains and two sections of the grate are shown in position on the main frame. The Renolds chains are fitted with hollow pin bearings through which mild steel supporting rods pass to stretch across the full width of the grate. These support the surface of the grate.



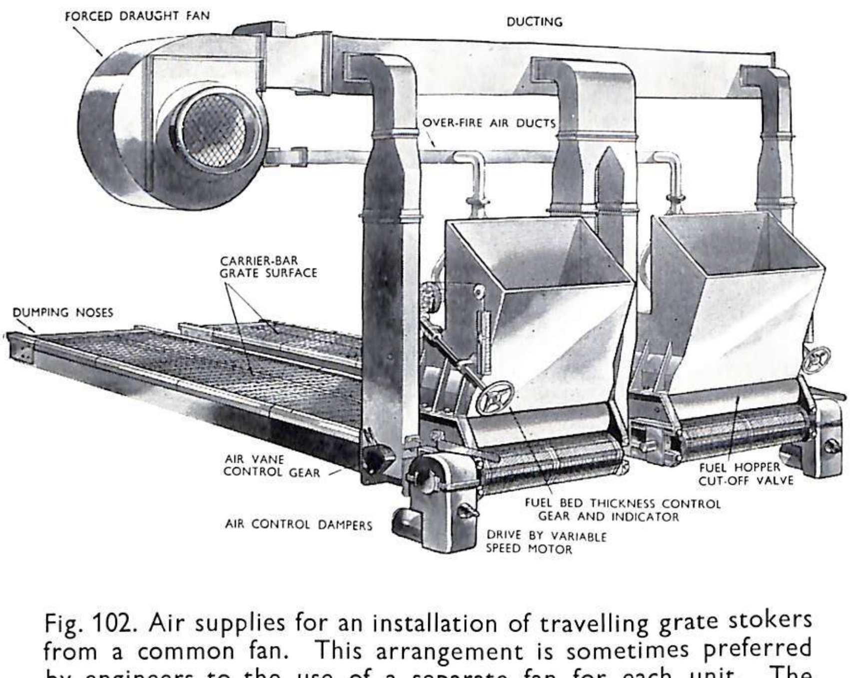



Fig. 102. Air supplies for an installation of travelling grate stokers from a common fan. This arrangement is sometimes preferred by engineers to the use of a separate fan for each unit. The choice depends largely on the site.

*The drive* is by variable speed motor through reduction gears mounted on the stoker side frame. Adjustment of the grate surface and tension of the chains is effected by adjustable front shaft bearing blocks.

*The primary supply of air* may be by forced draught fan through ducting with a secondary supply taken from it and discharged from the ignition arch over the fire, or by a separate forced draught fan for each unit.

*Ash removal.* This is usually by hand, and there is a design by which the ash may be discharged over dumping noses through a hopper on to a conveyor made of overlapping slats mounted on Renolds chains and driven by sprockets mounted on the driving shaft at the front.

*Conveyor adjustments.* There is provision to adjust the tension in the chains of the grate and of the ash conveyor, and the grate may be withdrawn for inspection, leaving the hopper and ignition arch in place. The ash conveyor may also be withdrawn as a separate unit.

# CHAPTER VIII

## UNDERFEED STOKERS

The underfeed stoker is a motor-driven firing device which feeds solid fuel into the bottom of a firepot or retort, arranged in the combustion space of the boiler in which it is to be burned. The coal is stored in a bunker or hopper close to the boiler, and the stoker conveys it from this store to the boiler by an Archimedean screw (fig. 104) or by a reciprocating ram (fig. 107).

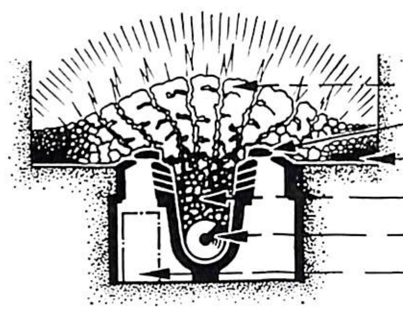



Fig. 103. A section through the retort and fuel bed of a small underfeed stoker. This is an elementary retort with a solid hearth.

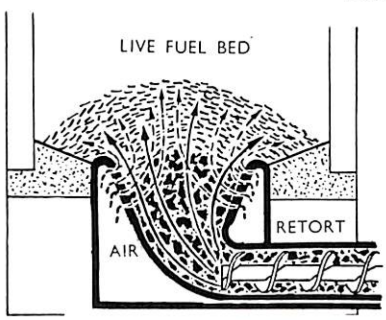



Fig. 104. A section through the retort of a small underfeed stoker fed by an Archimedean screw.

The feeding of fuel upwards from the underside of a fire bed, and of leading into it the air required for its combustion through ports arranged below the surface of the burning fuel, was first suggested by Dawson and Hawkins in 1816, but it was not until 1892 that this method was successfully applied to the firing of coal. The advantage obtained by this procedure is that volatile matter is driven off as the coal passes through zones of increasing

temperature, and when it reaches the surface only coke remains. The coke is incandescent and is burned off as it is moved towards the perimeter of the fire around which ash accumulates. Ash and clinkers are withdrawn at appropriate intervals by hand.

A well-designed machine, fed with a suitable grade of coal and effectively controlled, maintains a fire with a radiating incandescent surface which is never blanketed by raw coal. Heat losses due to opening the fire door, which occur with hand-firing, are avoided, and the loss of unburned carbon in ash is at a minimum.

## COMBUSTION IN UNDERFEED STOKERS

An underfeed fuel bed has been defined by Nicholls as one in which fuel and air move in the same direction, in contrast to an overfeed fuel bed in which fuel and air move in opposite directions, or with a cross-feed fuel bed in which the fuel moves in a direction at right angles, that is, normal to the flow of air.

The ideal conditions for an underfeed fuel bed are:—

(1) unrestricted ignition, the fuel being free to ignite as quickly as its burning characteristics permit;

(2) fuel of a uniform range of sizes in proportions such that the resistance to the flowing air is the same throughout a bed, with ignitability also uniform;

(3) a uniform distribution of air and fuel to all parts of the bed;

(4) uniform depth;

(5) no wall effects, no coking or caking, no clinkering and no blow-holes.

The fuel bed in the retort of an underfeed stoker is underfeed only in the sense that both coal and air travel through the retort roughly in the same direction, but at any point in the retort air flow may cross that of the coal, giving a combination of underfeed and cross-feed burning. The probable direction of fuel and air flow in different parts of such a bed are indicated in fig. 104. The directions coincide for only a limited distance in the bed. In some circumstances, as with high rates of fuel feed, even overfeed burning may be appreciable.

The extent to which the different types of burning occur depends upon the position of the ignition zone. Observation has confirmed that pure underfeed burning does not occur, and that the extent to which the different types of burning occur is a function of stoker design and of the feed and air rates. Overfeed and cross-feed burning increases the burning capacity of a stoker beyond that which is possible with pure underfeed burning. The maximum burning rate cannot for this reason be accurately predicted on a theoretical basis.

### The Effect of Crushing and Segregation.

Studies of the crushing and segregation of coal in underfeed stokers by Sherman and Kaiser have shown that the distribution of sizes to different parts of the retort is not uniform, and that a greater quantity of coal is fed to one part of a retort than another. This follows because segregation and

the breaking down of the proportions of the constituent sizes inevitably occur in handling, in feeding from hoppers, and in the final distribution within the retort.

The effects of segregation, uneven fuel feed, and crushing are that segregation leads to a variable resistance through the fuel, causing an unequal distribution of air in different parts of the retort, while an uneven fuel feed creates a higher demand for air in some parts of the bed, which cannot be met because of the greater resistance; crushing leads to greater segregation and reduces both the ignition and burning rates.

**The Distribution of Air.**

The arrangement of air ports at the sides does not allow a uniform distribution of air, and wall effects, coking, caking, clinkering and blow-holes are always present to a greater or less extent. The burning rate of a given coal at different parts of the retort thus varies, and a secondary, non-uniform movement of pieces and particles occurs because of this. Combustion cannot, therefore, be symmetrical with respect to the centre and is usually most intense at the rear. The gases rising from the centre and rear thus contain combustibles which have to be burned over the fire.

The combustion of coal and coke in an underfeed stoker, even under conditions of continuous operation, is not, therefore, a stable process, the burning rate for the fuel bed as a whole varying in a more or less cyclic manner with that at the centre of the bed.

**Thickness and Temperature of Combustion Zone.**

The thickness of the combustion zone ranges from $3\frac{1}{2}$ to 5 in. with coke, from 3 to 6 in. with free-burning coals, and from 6 to 9 in. with highly coking coals. The ignition level is near the top of the retort with coke; from 2 to 4 in. below the top of the retort at the edges to well above the top of the retort at the centre, with a free-burning coal; and with highly coking coals ranges from the top of the retort upwards. An increase in excess air reduces the thickness of the combustion zone.

**Effect of Fines on Combustion.**

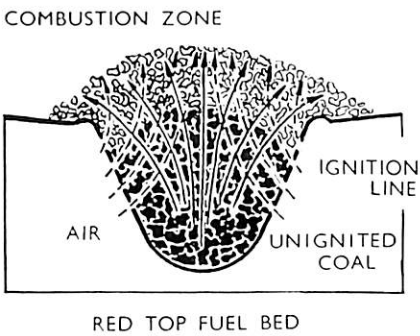
The removal of fines from coking coals does not materially affect their burning characteristics during continuous operation. The resistance of fines to air flow at low rates, other factors constant, is greater than for coarser sizes, but mixtures of fine and coarse grades may have a higher resistance than their size fractions taken separately. This is because mixing decreases the porosity of the bed.

The relatively high percentage of fines which is delivered to the rear of a retort of the standard shape results in an increase of the burning rate and hence to less excess air in this region. The zone of highest temperature therefore occurs at the back of a retort and may exceed that at the front by as much as 500° F.

**Red-Top and Black-Centre Burning.**

The fuel bed as produced at appropriate coal and air rates is uniformly incandescent at its surface. This is called "red-top" burning, and occurs at low fuel feed and air rates, and at high rates of fuel feed with low excess

air (see fig. 105). But if the air rate is too great, an area or areas of unignited coke appear at the surface. This is called black-centre burning (see fig. 106). Black-centre burning may also occur due to the formation of "coke trees" from strongly coking coals; that is, of formations of coke which cannot be burned satisfactorily at the relatively low air rates used with underfeed stokers. The upper limit of the air rate is fixed by the need to avoid committing a public nuisance by grit emission. Black-centre burning is thus accompanied by smoke, and attempts to remedy it by using still higher air rates result in a further increase in the grit emitted.



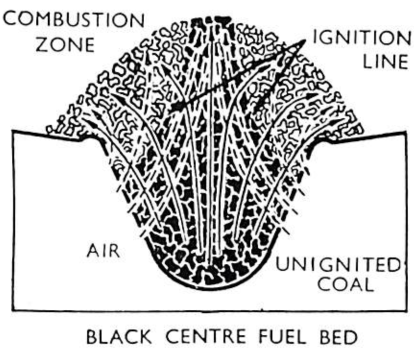




Fig. 105. Red-top burning. Fig. 106. Black-centre burning.

The patches of ignited coke are shaded and the patches of unignited coke are not. The ignition level conforms to the break between the two. The directions of fuel feed and air flow are shown by solid and broken arrows, respectively. If, at equilibrium, the ignition level falls within the fuel bed, burning will be red-top; if it breaks the surface black-centre burning results.

The combustion zone for red top burning in fig. 105 is uniform in thickness, but as the ignition level may be at any height in the fuel bed, from the lowest tuyere to the surface of the bed, this may vary and still produce an incandescent fuel bed. When the ignition level breaks through the top of the bed to give black-centre burning, the coke in the centre of the bed is fed to the combustion zone laterally.

## THE CLASSIFICATION OF UNDERFEED STOKERS

There are two main types of underfeed stokers:—

(1) The screw type (fig. 104).

(2) The ram type (fig. 107).

The two are distinguished by the way in which coal is transferred from the storage hopper and thrust to the surface of the fuel bed. In both designs, the coal is burned in a retort with a trough-shaped base which diverts the flow of fresh coal upwards into the burning coal, and an upper section or row of air ports (tuyeres) through which combustion air passes.

The details of retort design vary with different manufacturers and the application of the stoker, but a minimum retort area in relation to the rate of coal feed is specified in B.S.S. 746.

The screw-feed type is made with a range of coal feeding capacities from 12.5 to 1,200 lb. per hour, and the range with the ram-feed is from 250 to 750 lb. per hour. Both types are made in three styles, called the standard hopper, the flue and the bunker models respectively.

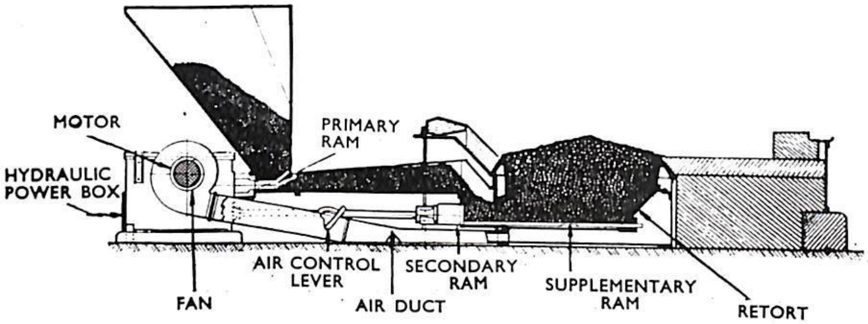



Fig. 107. A section through a retort of a small underfeed stoker fed by reciprocating rams.

In the standard hopper model the coal hopper is an integral part of the unit. Typical designs are shown in figs. 108, 111, 114 and 115. The bunker model feeds coal direct from the main storage bunker (figs. 119 and 121 are examples), and the flue model, of which fig. 116 is an example, is used to fire horizontal shell boilers. The bunker model reduces fuel handling costs, and the coal feed tube and air duct can be frequently run underneath the firing floor, leaving the boiler front completely unobstructed. A bunker-feed model of the ram type is not made.

In this survey we are concerned principally with the application of underfeed stokers to the firing of vertical boilers.

## FEATURES OF UNDERFEED STOKERS

**The hopper** capacity is determined by the requirements of operation and site considerations.

**The conveyor screw or worm** must be tough and highly resistant to corrosion and abrasion. Chrome-molybdenum or chrome-manganese alloy steel castings, cast-iron flights threaded on to steel shafts, and mild steel flights mounted on steel shafts are used, and when in accord with the British Standard, give efficient service for at least one year.

The largest size of coal which can be accommodated without crushing is determined by the free space between the flights, and a relation between pitch and speed is chosen by designers to give minimum power consumption and minimum fuel degradation in transit. A smaller pitch along the section of the screw which receives the coal from the hopper does much to eliminate packing in the coal feed tube. When the coal has to be conveyed a relatively long distance, a U-shaped trough with detachable cover plates is recommended.

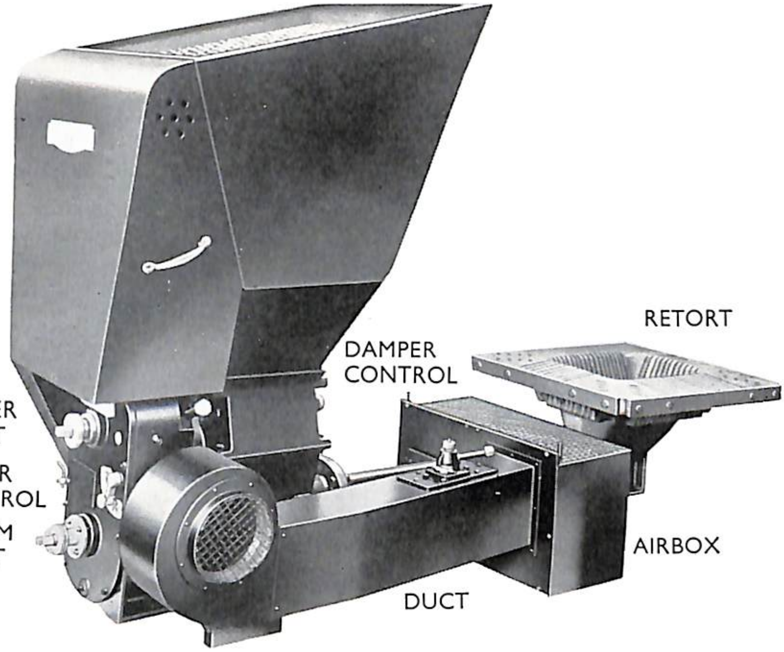



Fig. 108. A Hodgkinson "Phoenix" screw-type underfeed stoker.
This differs from the standard screw-type in that coal passes from the hopper into a fluted feeder drum, the speed of rotation of which governs the rate at which coal is fed into the hopper base, from which it is conveyed to the retort by an Archimedean screw or conveyor worm which revolves at a constant speed. The capacity of the screw is greater than the maximum rate of feed. The coal tube is therefore only partially filled at any time. Jamming is thus less likely to occur. A hinged spring loaded feeder plate prevents coal flooding the base of the hopper.

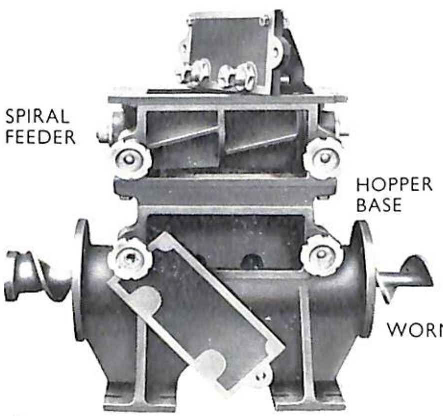



Fig. 109. The fluted feeder drum of the Hodgkinson "Phoenix" stoker with cover removed.
A second cover shown partly removed gives access to the base of the coal feed hopper and the worm. The covers can be seen in position in fig. 110.

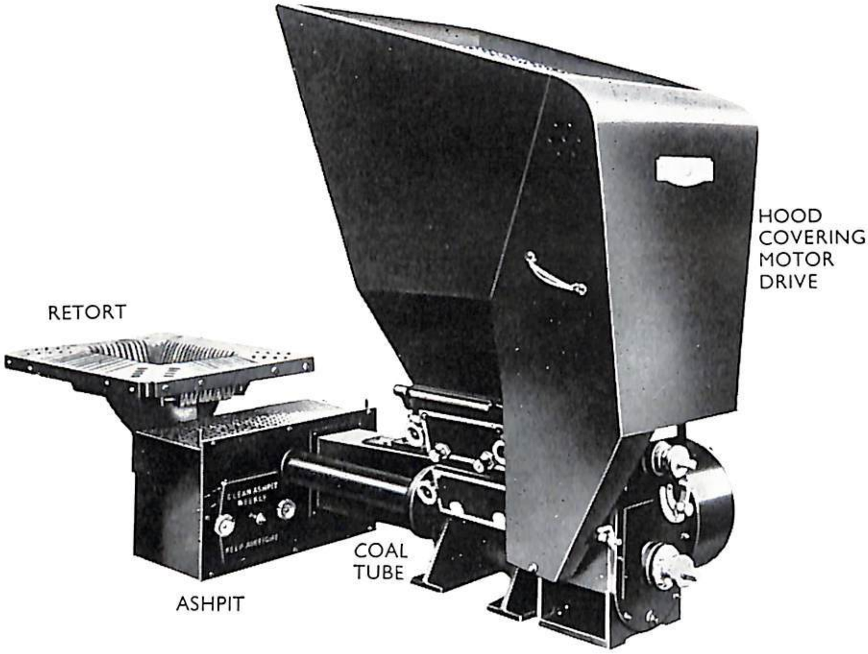



Fig. 110. The "Hodgkinson" screw type hopper model.
Note the door for the removal of ash which may fall through the tuyeres into the air box. This should be cleared weekly.

**The drive.** Power to drive the fan and the coal feed is usually supplied by an electric motor running at 1,440 r.p.m., and as the speed of the coal feed screw may be only a fraction of a revolution per minute, a gearbox with a high reduction ratio is interposed. Motors embodying brush gear are totally enclosed up to 1 h.p., and larger motors are given drip-proof protection or are totally enclosed. To comply with British Standard 746, motors used with underfeed stokers must conform with B.S. 168 for the electrical performance of industrial electric motors with Class A insulation, and with B.S. 170 for the electrical performance of fractional horse-power motors.

Overload protection must be provided on at least one pole with single-phase D.C. motors, and on at least two poles with two-phase and three-phase A.C. motors.

**Power transmission** units are totally enclosed, with parts made to ensure interchangeability, and all moving parts run in oil. The reduction may be obtained by a worm and worm wheel which operate a pawl and ratchet mechanism. This gives the feed screw an intermittent rotary motion. Means may be provided to select one of a number of rates of feed. A typical unit incorporating a pawl and ratchet drive is shown in fig.122. Fig 124 shows a rachet drive with auto-selection. The pulling motor (fig. 125) is operated by a pressurestat on the steam supply. When the

pressure falls by a pre-set amount an electric circuit is completed and current flows to the motor, which makes half a revolution. In doing so the selector plate is moved a pre-set number of teeth through the levers shown, thus increasing the action of the driving pawl; the speed of the feed worm, and hence the rate at which coal is supplied. The pre-set ratio between coal and air being also maintained.

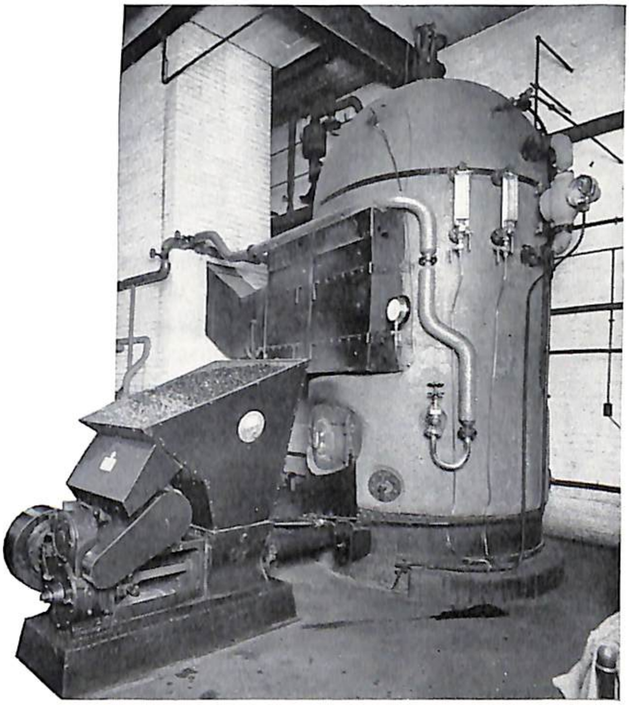


Fig. 111. The "Mirrlees" standard hopper model.

Some ram type stokers are fitted with electro-hydraulic transmission units. The rams are coupled to pistons operated by oil under pressure. Oil is admitted to, and released from, the operating cylinders of the primary and secondary rams alternately through reversing valves. The pistons are returned through racks by a common idler pinion: thus, when the primary ram is delivering coal, the secondary ram is returned to the start and vice versa. The feeding rate is controlled by a needle valve and an automatic relief valve is provided to limit the pressure within the system.

**Air supply** is usually by a low-pressure centrifugal fan of the multivane (forward blade) type. The static head to be overcome by the fan is the total resistance of the ducts, tuyeres and fire bed. This varies from 0.75 in. to 2 in. w.g. The fan is usually mounted on an extension of the gearbox worm shaft (the only high-speed shaft in the box). Control is by hand by a damper at the fan inlet, or in the discharge ducting, or it may be automatically controlled.

## RETORT DESIGN

The design of the retort determines whether coal can be burned smokelessly or not. The tuyeres are made from heat-resisting cast-iron, are individually renewable and are designed to present the largest possible area to the cooling effect of incoming air. The wind box under the tuyeres is of cast-iron, and provision is made to allow the removal of ash which may find its way through them (see, for example, fig. 110). The hearth surrounding the air ports may be of firebrick or cast-iron deadplates or liveplates (perforated).

The principles governing retort design are:—

(1) Air and coal should be so introduced into the retort that unrestricted ignition occurs throughout the ignition zone as rapidly as the burning characteristics of the coal will permit.

(2) The area of live fire bed should be as large as possible. The limits are fixed by the burning characteristics of the coal, and the distribution of air in the space available. There is therefore a limit to the grade of coal which can efficiently be used with any design.

(3) Sufficient space must be left around the perimeter to accommodate ash and clinker, and thus provide for a reasonable period between the cleaning operations.

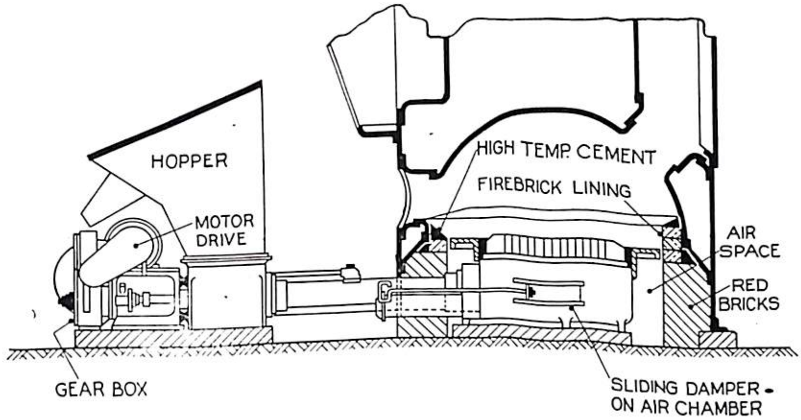
The retort shown in fig. 112 is rectangular in plan, and may be surrounded by a solid refractory hearth, as indicated, or by air-cooled deadplates to complete the grate. This type is in general use with *small* vertical boilers.

With vertical boilers of moderate size, the first principle may be met by surrounding the retort with a grate through which air may be supplied, thus extending the area of the live fire bed. This arrangement is shown in fig. 113. The same effect is obtained in a restricted space by widening the tuyeres and providing several rows of them. The rate of travel of burning coal towards the perimeter of the grate is limited by the characteristics of the fuel, particularly by its caking properties, and the maximum permissible area of live fire bed is fixed by the occurrence of black-centre burning. This is particularly liable to occur with small coal of high inert content or with coal which does not cake.

An increase in the live fire bed may be obtained, when the shape of the combustion chamber permits, by lengthening the retort. It is, however, difficult to ensure a uniform distribution of coal throughout a long retort. One way of overcoming these difficulties is by using twin stokers, with retorts of normal length, in place of a single stoker with an abnormally long retort. Experience has shown that such appliances operate well and can burn a wider range of fuels than the single-retort type (see fig. 123).

Alternatives are to use live plates under forced or natural draught as in fig. 113, or a single feed screw with a duplex burner as in figs. 126 and 127.

These designs secure a large area of a uniformly incandescent highly radiating fire bed surface at a reasonably low combustion rate, and are specially suitable for burning coal of relatively high ash and fines content. The larger grate area thus obtained, with more even distribution of low-pressure air, reduces wear and prevents excessive clinker formation. These general principles are equally applicable to stokers for horizontal shell



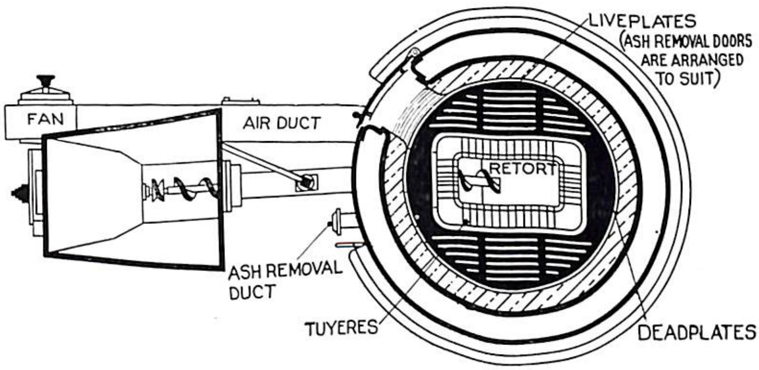




Fig. 112. A "Mirrlees" screw-type standard hopper model applied to a vertical multitubular boiler.

The firebed is extended by live plates built out from the sides of the retort to the walls of the boiler, as in fig. 113. Doors are arranged for the removal of ash from beneath the live plates. There is a duct for the removal of ash also from the air chamber around the retort. The rate of coal feed is governed by the speed of the screw.

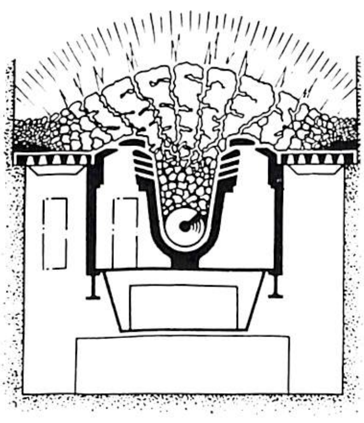
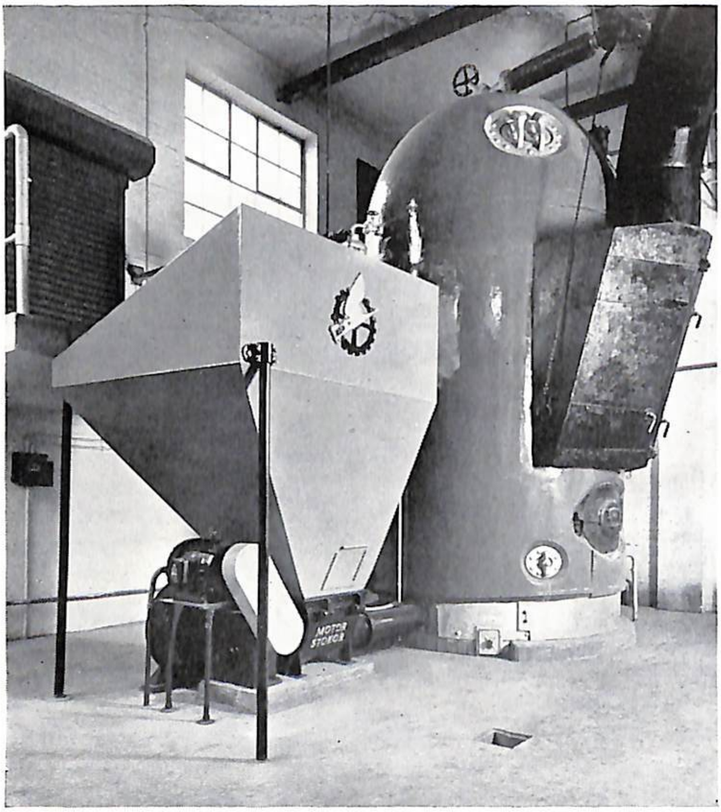


Fig. 113. A retort surrounded by a grate as with a vertical boiler.

The air duct is divided into two sections; one to supply the tuyeres and the other the surrounding grates. These provide additional area on which combustion can take place, ash and clinker being easily removed from these air-cooled surfaces.



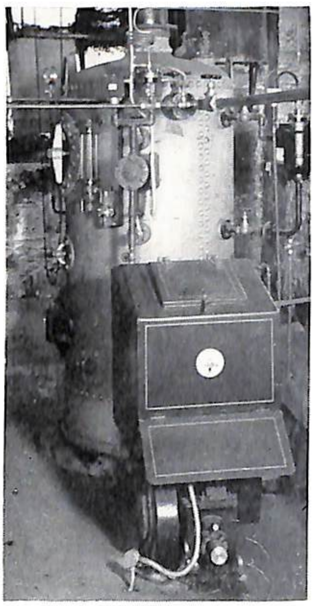



Fig. 114. A "Hopes" screw-type standard hopper "motor stoker" applied to a vertical multitubular boiler. Coal is tipped direct from a road-wagon into the hopper.

Fig. 115. A Bigwoods "Unicalor" screw type standard hopper model applied to a small vertical boiler.

boilers, but they have to be specially constructed to fit into the flues of this type of boiler (fig. 116). The retorts are longer and narrower than those used for vertical boilers. The retorts of stokers for horizontal shell boilers end at a firebrick wall, and the front plates are lined with refractory material.

## COMBUSTION CHAMBERS

The level of the retort relative to the boiler crown must take account of flame clearance, the volume of the combustion chamber, and provision for clinkering. The boiler shell, where it is not water cooled, must be protected by a firebrick lining of ample thickness and of sufficient height to give adequate protection to the mud ring. Openings which are left in this lining for cleaning purposes must be spanned by a sprung arch, as slabs are not satisfactory. They are liable to crack and collapse, and are more susceptible to mechanical damage.

## THE FLUE-TYPE STOKER

A Riley flue-type stoker applied to a Lancashire boiler is shown in fig. 116, and is an example of this type of stoker.

The unit is self-contained and has a variable speed gearbox with automatic control of coal and air. The conveyor worm is in two parts: the section from the gearbox to the retort consists of a solid steel shaft fitted

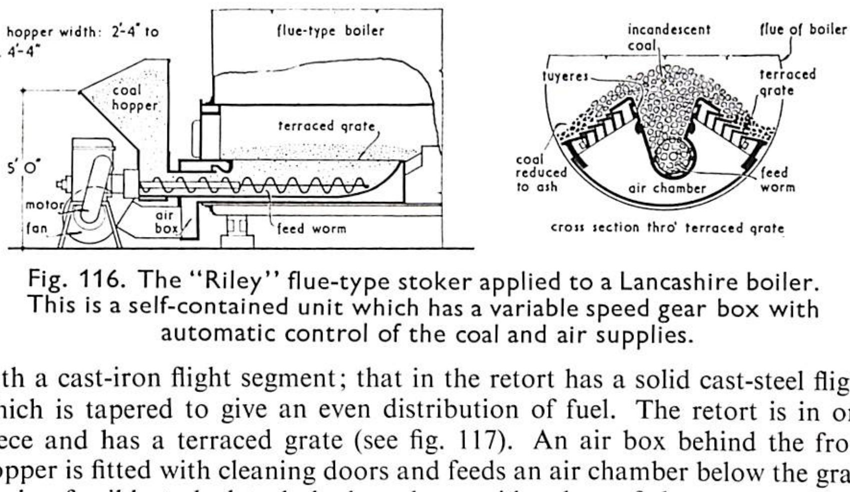



Fig. 116. The "Riley" flue-type stoker applied to a Lancashire boiler. This is a self-contained unit which has a variable speed gear box with automatic control of the coal and air supplies.

with a cast-iron flight segment; that in the retort has a solid cast-steel flight which is tapered to give an even distribution of fuel. The retort is in one piece and has a terraced grate (see fig. 117). An air box behind the front hopper is fitted with cleaning doors and feeds an air chamber below the grate made of mild steel plate bolted to the outside edges of the grate and bent to a semi-circular shape to suit the curvature of the flue. An air-tight joint is not, therefore, required between the stoker and the boiler flue. A forced-draught fan is connected by ducts to the box.

The adjustment of the coal feed is effected by the movement of a pawl lifting plate by a pulling motor which is automatically controlled by a pressurestat, the air quantity being adjusted at the same time (fig. 125). The normal hopper capacity is 650 lb., and the minimum draught required over the fire is 0.15 in. w.g. Lubrication of all parts of the gearbox is effected by a small pump operating in the oil sump.

Coal between 2 in. and $\frac{1}{8}$ in. in size is recommended for use with these machines, or a graded coal, such as singles, beans or peas.

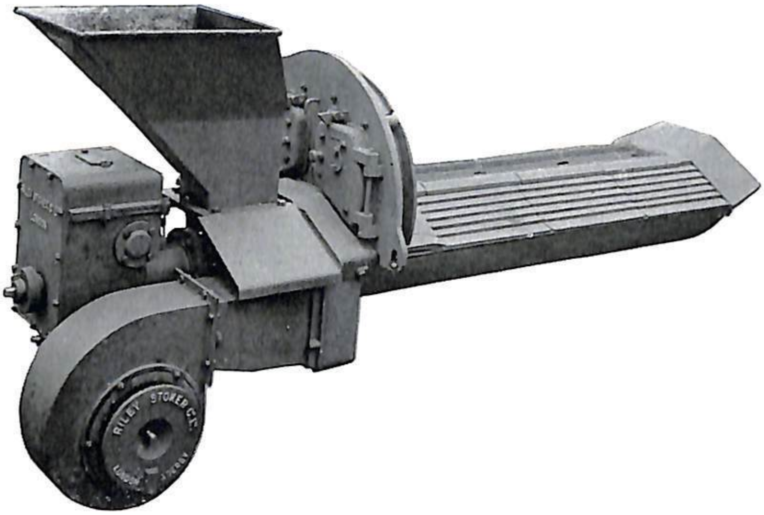


Fig. 117. The terraced grate bars of the "Riley" flue-type stoker overlap so that air enters the fuel bed horizontally. This prevents ash sifting through the air ports into the air box.

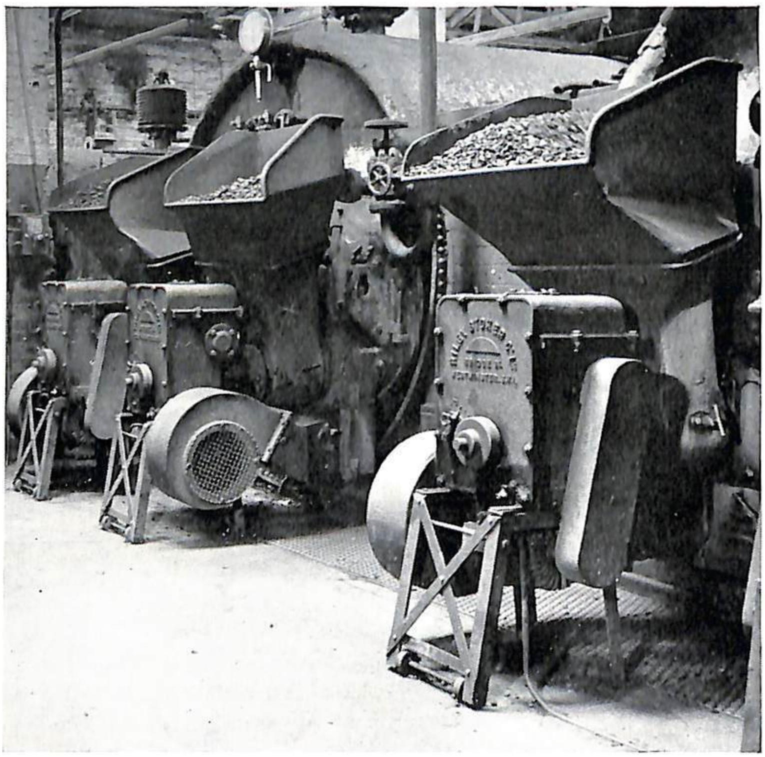


Fig. 118. A typical installation of a "Riley" flue-type stoker.

## THE BUNKER-TYPE STOKER

*Bunker-feed stokers* are of two kinds: those which convey the fuel from the bunker to the retort by a continuous screw (figs. 119 and 120) and those in which the coal is conveyed in two stages: the first screw conveying coal from the bunker to a transfer box, and the second from the transfer box to the retort (fig. 121). The illustrations are of typical machines of this class.

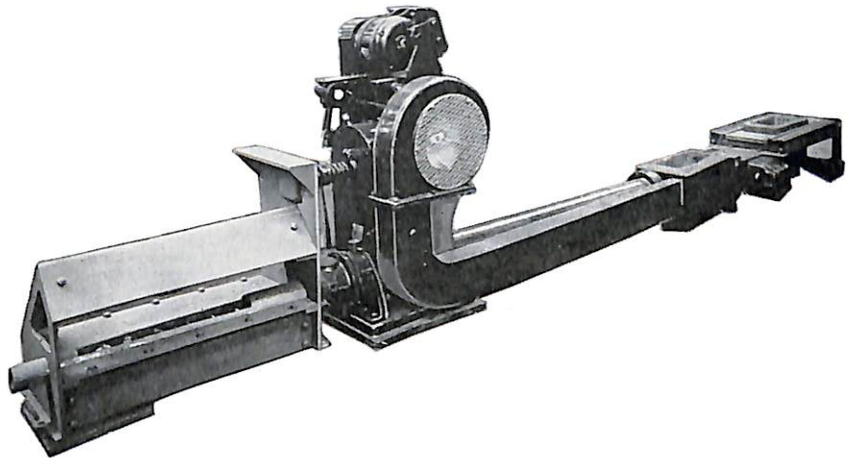


Fig. 119. A bunker-feed stoker.

The coal is drawn from the bunker by a graduated pick-up screw which transfers it to a revolving tube, inside which is a fixed helix down the blades of which coal slides and is thus transferred systematically to the boiler front. The pick-up and final delivery screws are connected to the tube and revolve with it. The drive from the gear box is by chain and sprockets to the periphery of the revolving tube. The tube may be of any reasonable length. The coal is measured into it and is not broken down in transit. This is made in nine sizes with capacities: 4 to 28 lb. of coal per hour to from 38 to 340 lb. of coal per hour.

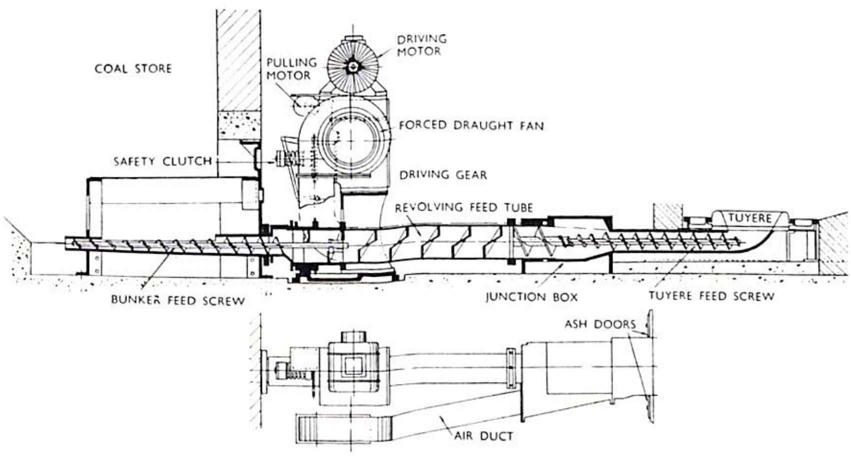



Fig. 120. A cross-section of the stoker shown in Fig. 119.

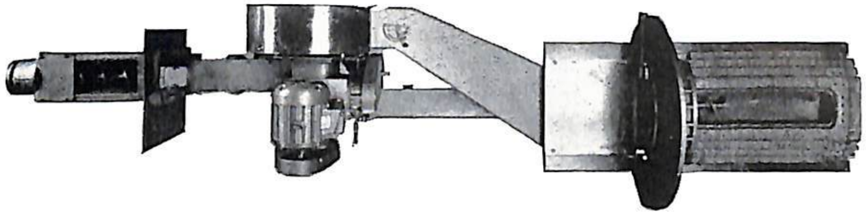


Fig. 121. Bigwood's "Unicalor" bunker-feed stoker.
Coal is transferred from hopper to retort in two steps. The first screw conveys coal from the bunker to a transfer box and the second screw from the transfer box to the retort. This machine is available for coal feed rates of 220 to 750 lb. per hour for firing tubular flue boilers. A similar design, suitable for installing in cast iron sectional and vertical steam boilers is available for the full range of 20 to 750 lb. per hour.

## AUTOMATIC CONTROLS

Underfeed stokers are usually supplied fitted with an automatic control as an integral part of the equipment. The two methods most widely used both operate on the "stop-start" principle.

A pressurestat is mounted on the boiler. This breaks an electrical circuit and stops the stoker motor when the steam reaches the working pressure, remaking the circuit when it has fallen by a pre-set amount. The rate of coal feed is set in excess of that required to meet the peak load, with an appropriate setting of the air control. The motor thus runs continuously at peak load, and at all other loads is started and stopped at intervals to maintain the working pressure. The coal feed and the air supply are both cut off when the motor stops.

A pressurestat or thermostat is caused to operate an air valve, which, by changing the air rate, disturbs a pre-set ratio of air to coal and operates a stop-start mechanism through which this ratio is maintained over cycles of one minute. That is, coal is fed for such a part of each minute as is required to maintain this ratio, whatever the air rate might become. A hand control is provided for use when starting up or in an emergency.

Other systems are based on continuously running stokers with control equipment which automatically selects a rate of coal feed and an air rate (between limits) to meet the load. In one arrangement a pressurestat, set to operate at a somewhat higher pressure than the one which normally takes control, stops the stoker if the lowest rate of coal feed is more than sufficient to meet the load. In another device the quantity of coal delivered to the screw is regulated by a small modulating motor, governed by a pressurestat and linked with an air control valve in the fan inlet.

Another arrangement of controls secures a constant air/fuel ratio by interconnected air and coal metering devices operated by a pressurestat. The air/coal ratio is adjusted by hand to suit the requirements of the fuel which is being burned. Indicators showing the weight of coal fed in pounds per hour and the air flow in cubic feet per minute are supplied, and these, with the control valve and air/fuel ratio adjustment, may be housed in a casing situated some distance from the stoker.

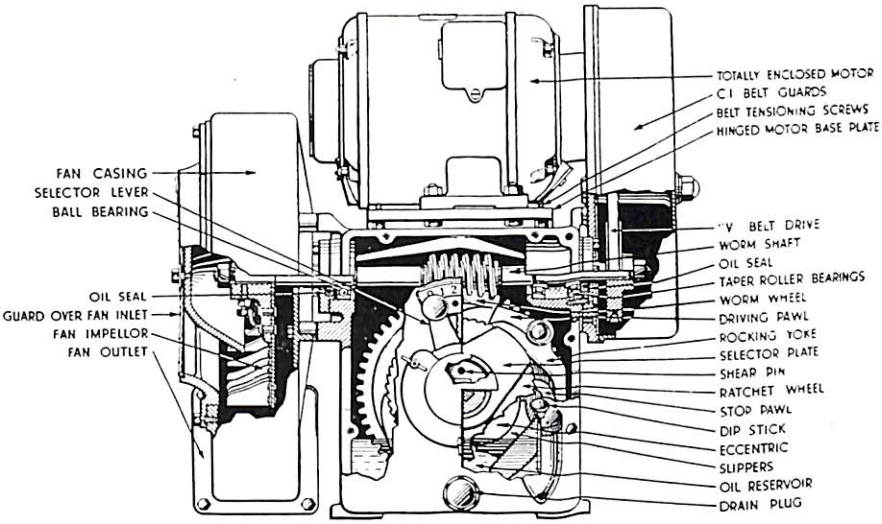



Fig. 122. The "Unicalor" drive.

Its essential features are: a V-velt transmits the drive from a totally enclosed electric motor to a worm reduction gear, from which the final reduction is obtained through an adjustable pawl and ratchet mechanism. This gives the choice of a range of feeds by adjustment of a selector plate or mask. All parts are interchangeable and an easily replaceable shear pin or a slipping clutch protects the mechanism against damage from an overload. The gears operate in an oil bath.

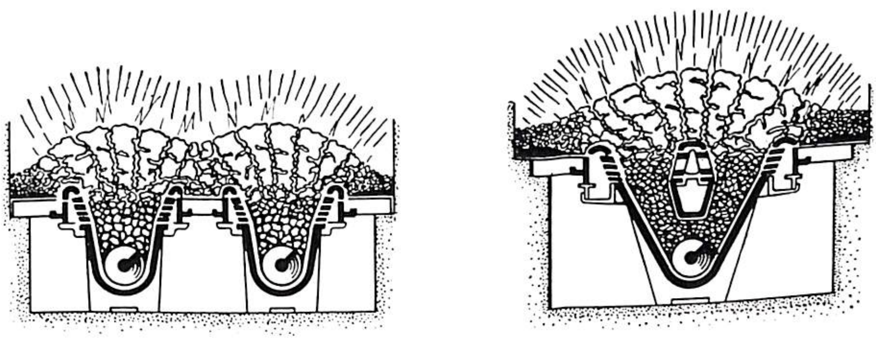


Fig. 123. Multiple retorts and a Duplex burner.

The extent to which the burning fuel will travel towards the perimeter of the grate is limited. To increase this distance by widening the mouth of the retort leads to black-centre burning. This is particularly liable to occur with small coals of high inert content or with non-caking coals. Multiple retorts have been introduced to overcome this difficulty.

Automatic air controls may be fitted to stokers operating on the "stop-start" principle, without automatic feed selection.

## SAFETY DEVICES

**High steam pressure and low water safety controls** should be part of the equipment of automatically fired steam boiler installations. The former stops the stoker if the steam pressure rises above the pre-set limit of control, and the latter if the water level falls below the water limit. Devices to give an audible warning if either of the safety controls come into operation are often added. A low water safety control should be fitted with a valve so that it can easily be blown down and tested, and the operating instructions should require this to be done at frequent intervals.

**Driving motors** are protected from damage due to overload by thermal or magnetic overload releases. These do not, however, protect transmission gear from the effects of a sudden obstruction in the coal feed screw. Mechanical damage of this kind is guarded against by an easily replaceable shear pin (see fig. 122) or by a slipping clutch in the transmission.

## OPERATION OF UNDERFEED STOKERS

**All makers supply detailed instructions for the installation of their equipment and for effecting the replacement of motors and spare parts. These should be followed.**

In general, when the stoker has been installed and the electrical connections have been completed, the gearbox is filled to the correct level with oil of the grade recommended by the manufacturers. (Shell C5 or a similar oil is usually specified.) This is sufficient for several months' run. The tension of the driving belt is adjusted, and the motor is switched on with the speed gear set at the maximum rate of coal feed. The feed worm should then drive the fan in the direction indicated by the arrow marked on the casing. The stoker should be run for a short time to check the operation of the mechanical parts.

There should be no leaks from the air chamber as, if the air pressure is lost, a poor, smoky fire will result. It is for this reason that the joints between the conveyor pipe at the tuyere supporting casting should be made tight with asbestos cement.

If electric leads are run in a conduit it must be made impossible for water to get into it.

Wet coal should not be used and care should be taken to see that coal is free from wood, coke, brickbats, nails and other foreign matter, as these may cause the feeder screw to jam.

### Starting up from Cold.

Open the chimney dampers, fill the hopper, close the air control valve and switch on the stoker. When coal has been fed up to the bottom of the air inlets, stop the stoker and light a fire (at the surface), placing a small amount of coal on top. Switch on the stoker at the lowest rate of coal feed. Gradually increase the coal feed and air rate until, as the fire grows, a bed 8 or 10 in. deep is ignited above the air ports. The air control valve is then

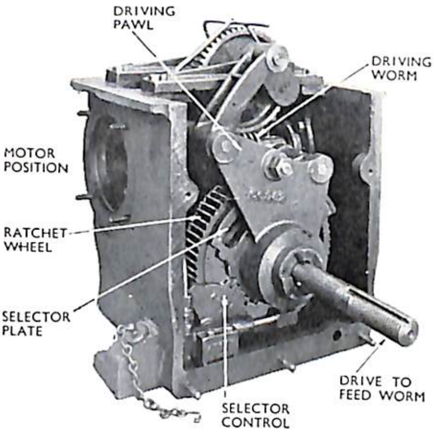



Fig. 124. The "Riley" gear box.

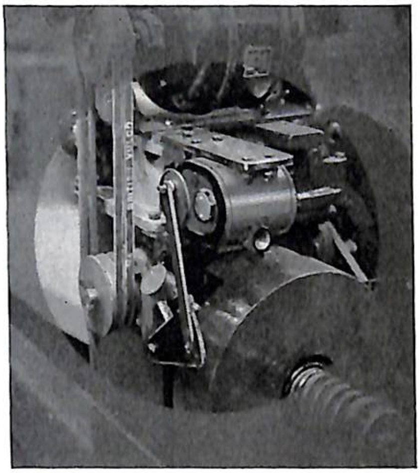


Fig. 125. The pulling motor used with the "Riley" gear box.

adjusted to maintain this with red-top burning. The fire should be well alight in a few minutes. It is often possible, with some fuels, to re-light the fire after a stoppage of a few hours by simply starting the stoker motor. Before starting up, see that all control rods and levers work freely if the stoker has been standing for some time.

**Chimney Draught.**

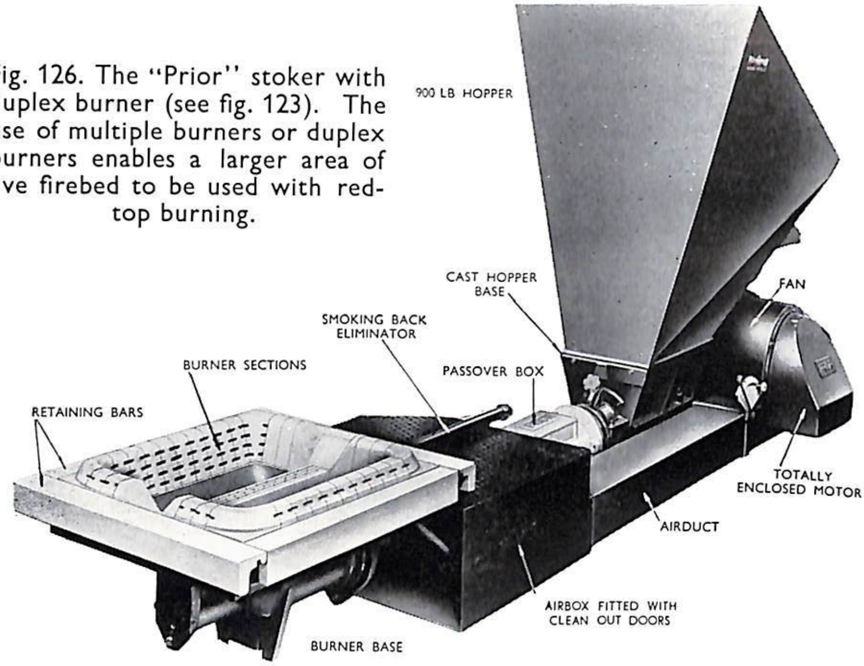
The chimney damper should be set to maintain a pressure in the combustion chamber slightly less than atmospheric. This is obtained by closing the damper until furnace gases begin to leak through the fire door, and then opening the damper carefully until smoke from a smouldering rag held at the fire door opening is just drawn into the furnace. The fire should not be allowed to burn down to below the top of the air ports or clinker will form and damage the tuyeres and feed worm. The maintenance of an incandescent fire bed of satisfactory thickness depends upon the correct adjustment of the coal feed, the air rate and the chimney draught.

**Regulation to Suit Load.**

The coal feed and the air supply should be set so that the stoker operates for about 50 minutes in each hour. Short periods of operation with long periods of inactivity should be avoided.

To keep the fire alight during long periods at no load, e.g. during the night, a kindling control is often installed. This may be a time switch set to cause the stoker to operate at a low rate of feed for, say, 10 minutes in each hour, or it may be a fluestat which starts up the stoker when the temperature of the flue gases falls below a pre-set minimum. The fire should be thoroughly cleared of clinker and ash and fed with fresh coal until a normal depth of fire has been built up, before the kindling control is switched

Fig. 126. The "Prior" stoker with duplex burner (see fig. 123). The use of multiple burners or duplex burners enables a larger area of live firebed to be used with red-top burning.



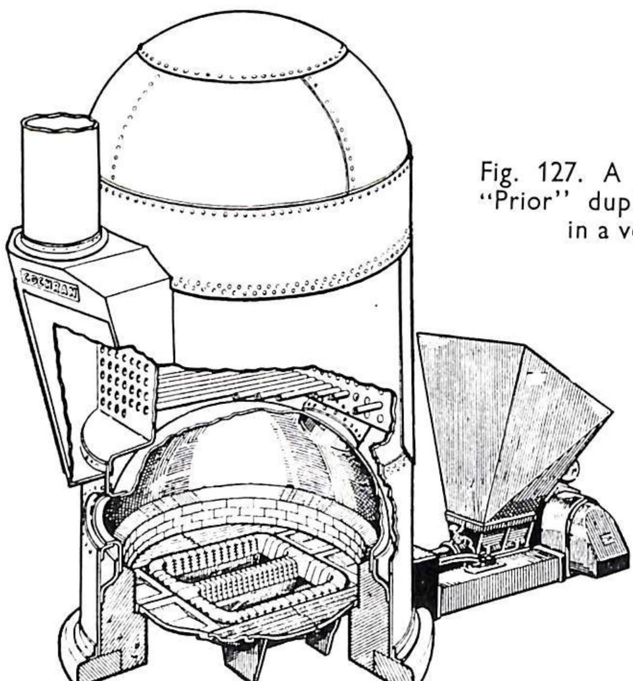



Fig. 127. A pictorial view of a "Prior" duplex burner installed in a vertical boiler.

on. The coal feed is then set at the minimum rate and the stoker control and chimney damper adjusted to suit. If a stoker is not fitted with a kindling control, the stoker is switched off after the fire bed has been prepared as above, the air control then being shut off and the chimney damper opening reduced.

**To Shut Down a Stoker.**

The stoker should not be stopped while there is a very hot fire on the grate. The fire should be first allowed to cool by gradually reducing the air pressure, as there is the danger of burning the tuyeres if the cooling air is suddenly cut off from a fire at a high temperature (i.e. white hot). Finally, the chimney damper must be closed, or air may be drawn into the furnace in sufficient quantity to keep the fire alight. This may work back into the retort and even into the coal hopper.

**Overload Protection Devices.**

The transmission gear of an underfeed stoker should be protected against damage due to overload by a shear pin or a slipping clutch. Overload may be caused by the feed screw becoming locked due to foreign material in the coal, by an accumulation of clinker over or within the retort, or by the formation of hard coke from a highly caking coal. To avoid repeated shearing of the pins the cause of overload must be found and removed. Foreign material (slate, stone, iron, etc.) in the coal usually jams at the entrance to the coal feed tube, and can be removed after taking off a small cover plate. Great force should not be used to clear a jam, the instructions of the makers being followed in this emergency. Obstructions due to clinker indicate that the fire should be cleaned more frequently. Formations of hard coke may be broken up to some extent by poking, but the only satisfactory solution is a change of coal. If the stoker worm runs "hard," try to find out why and remedy it.

Thermal overload coils are fitted in a stoker control box to prevent damage to the motor and possible burning out owing to an excess of current passing through it. These stop the motor in these circumstances. Should this happen an electrician should be called.

**Cleaning the Fire.**

Fires should be cleaned night and morning when a stoker is operated continuously over the 24 hours. Cleaning consists of the removal of large clinkers with tongs or with a rake or shovel. If the quantity of ash is not very great it may be left in the furnace until it is reduced to clinker. The stoker is switched off before cleaning is begun. The intervals at which ash and clinker should be removed depends upon the quantity of ash in the coal and the rate of burning, and is ascertained by experience. Clean fires are essential if the efficiency of a stoker is to be maintained.

**Smoke Elimination.**

To prevent smoke and fumes leaking back through the coal feed tube and hopper into the boiler-house, a supply of air is taken from the air duct

to the coal feed tube. This may be fitted with a valve, which is locked in the position required to allow sufficient air to pass to prevent this leakage.

**Motor Overload Protection.**

This is installed in the control box and may be a magnetic or thermal overload release. When such a device operates it should not be reset until after one minute has elapsed. Should the motor then fail to start, the fuses are examined, and if intact the cause of the overload should be found and removed.

**Emergency Hand-Firing.**

If hand-firing is resorted to, the base of the retort and the coal feed worm should be protected by firebricks built up within the retort to the level of the bottom of the tuyeres. The feed gear should be set to neutral and the motor started up to operate the fan only. If a breakdown occurs in the motor, the air controls are opened to a maximum and the cleaning covers are removed from the air ducts under the retort to allow as great a natural draught as possible.

## MAINTENANCE (INCLUDING LUBRICATION)

A clean, efficient fire cannot be maintained if the air chamber is dirty or if the air is leaking from it. The air duct cover should therefore be removed each week and accumulations of dust removed, with the fan stopped.

At the end of the first month the gearbox should be washed out with flushing oil and refilled with oil of the grade recommended by the makers. The oil level in the gearbox should be checked monthly and topped up if necessary. The gearbox should be washed out with flushing oil each year. Maker's instructions should be followed in the application of a small amount of grease to parts such as the thrust washers at the back of the gearbox, or a worm bearing collar.

The tension in the belt drive should be checked monthly, and the condition of the retort, tuyeres, deadplates and brickwork examined periodically. If the stoker is out of operation for a prolonged period, the hopper, coal tube and burner should be emptied to prevent corrosion, and the motor operated occasionally. If this is not done, wear due to corrosion may be greater than that due to operation. The inside of the hopper should be given a coat of anti-corrosion paint every 12 months.

# BIBLIOGRAPHY

The principal references are:—

Section three of the British Standard glossary of terms used for solid fuel burning appliances.

*Fuel Research Technical Papers*, Nos. 53, 54 and 55. H.M. Stationery Office.

*The Thermal Efficiency of a Hand-fired Natural-draught Lancashire Boiler*, by T. F. Hurley and W. J. Sparkes. Proc. Inst. Mech. E. 162, No. 1.20.

*The Influence of Certain Factors on the Performance of a Lancashire Boiler*, by E. G. Ritchie and N. Y. Kirov. Proc. Inst. Mech. E. 162, No. 1.27.

*Mechanical Stokers for Shell Type Boilers*, by A. C. Dunningham and B. M. Thornton. Journ. Inst. Fuel XVI. 96.

*Cooling Firebars in Industrial Furnaces and Boilers*, Fuel Efficiency Bulletin No. 20 of the Ministry of Fuel and Power.

*The Efficient Use of Fuel*. H.M. Stationery Office.

*Underfeed Combustion*, by J. Nicholls. Bureau of Mines Bulletin 378.

*Boiler Draught Production by means of Steam Jets*, by S. F. Benson. Proc. Inst. Mech. E. 153, No. 9.

*Total, Recoverable and Returnable Heat in Combustion Gases*, by P. O. Rosin, Chapter 1 of "Waste-Heat Recovery from Industrial Furnaces."

*Mechanical Stokers for Shell Boilers*, by H. E. Pearsall, and *Underfeed Stokers for Firing Steam Boilers*, by E. L. Tinley; Fuel and the Future, Conference, Vol. I. H.M. Stationery Office.